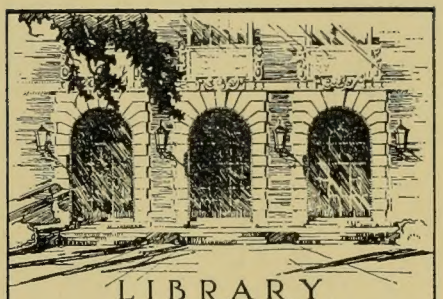

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NATURAL HISTORY
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ILLINOIS STATE LABORATORY

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VOLUME IX

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STEPHEN A. FORBES

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OF

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URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. OCTOBER, 1910 ARTICLES I–II.

ART. I. ON THE COMMON SHREW-MOLE IN ILLINOIS

BY

FRANK ELMER WOOD, A.B.

ART. II. A STUDY OF THE FOOD OF MOLES IN ILLINOIS

BY

JAMES A. WEST, A.M.

NATURAL HISTORY SURVEY
SEP 9 1969
URBANA

ARTICLE I.—*On the Common Shrew-mole, Scalopus aquaticus machrinus (Rafinesque), in Illinois.* By FRANK ELMER WOOD.*

There are two species of moles in Illinois: one, the starnose mole, *Condylura cristata* (Linnæus), is found sparingly in the northern part of the state; the other, known as the common or shrew-mole, *Scalopus aquaticus* (Linnæus), is the one with which this paper deals. It is distributed throughout most of the state, and apparently all our specimens may be referred to the western subspecies *machrinus* (Rafinesque).

The general range of the species, under various forms, extends over most of the eastern half of the United States. Its northern boundary is a line running from the southern point of Maine westward through New Hampshire, Vermont, New York, Ontario, and Michigan, and thence northwestward to a point on the Red River of the North near the Canadian boundary. Its western limit is near a line from that point to the mouth of the Rio Grande. The mole is found also for a short distance along the Gulf of Mexico, but not in southern Florida. Over this range there is considerable variation in size, color, and some other characters. In general, specimens from the arid regions of the West are lighter in color than those from sections in the east and south which have a moister climate. The smallest variety is found in Florida, and, judging from data at hand, specimens from Illinois attain the largest average size. In the Atlantic States northern specimens average larger than southern ones, and it is true in general for all states east of the Mississippi that eastern specimens are smaller than western ones from the same latitude. There appears to be considerable variation in size even within the state as is shown by the following tables.

True gives the average length of six specimens from Illinois as follows: total length, 188.7; head and body, 154.9; and tail, 33.8. Apparently these specimens were all from the western border of the state. This would indicate a gradual increase in size from east to west across the state, and that the maximum size was reached near or beyond the Mississippi River.

*Some matter on the mole, additional to that used in the present article, may be found in "A Study of the Mammals of Champaign County, Illinois," by F. E. Wood, published in May, 1910, as article 5 of Volume VIII of the Bulletin of this Laboratory.

MEASUREMENTS OF TWENTY-SEVEN ADULT SPECIMENS FROM CHAMPAIGN COUNTY

Acc. No.	Sex	Length					
		Total		Tail		Head and Body	
		mm.	in.	mm.	in.	mm.	in.
37761	Female	168	6.62	33	1.30	135	5.32
37762	Female	167	6.58	32	1.26	135	5.32
37814	Female	178	7.02	32	1.26	146	5.76
37984	Female	187	7.34	32	1.26	155	6.08
37985	Female	190	7.50	40	1.58	150	5.92
37986	Female	173	6.83	31	1.22	142	5.61
38219	Male	182	7.17	34	1.34	148	5.83
38235	Female	167	6.58	30	1.18	137	5.40
38318	Male	197	7.78	31	1.22	166	6.56
38347	Female	190	7.50	36	1.42	154	6.08
38348	Female	182	7.17	33	1.30	149	5.87
38349	Female	176	6.94	33	1.30	143	5.64
38351	Male	187	7.50	32	1.26	155	6.24
38352	Female	181	7.13	37	1.46	144	5.67
38353	Female	187	7.50	37	1.46	150	6.04
38354	Male	196	7.74	42	1.64	154	6.10
38355	Female	172	6.79	38	1.50	134	5.29
38356	Female	180	7.10	28	1.10	152	6.00
38357	Female	181	7.13	36	1.42	145	5.71
38362	Female	184	7.24	34	1.34	150	5.90
38366	Female	182	7.17	32	1.27	150	5.91
38367	Female	178	7.02	37	1.46	141	5.56
38368	Female	179	7.06	34	1.34	145	5.72
38369	Female	167	6.58	26	1.02	141	5.56
38375	Male	184	7.24	36	1.42	148	5.82
38377	Male	202	7.97	36	1.42	166	6.55
38480	Female	182	7.17	36	1.42	146	5.75
Averages		181	7.13	34	1.34	147	5.79

MEASUREMENTS OF THIRTEEN ADULT SPECIMENS FROM JACKSONVILLE, ILLINOIS

Acc. No.	Sex	Length					
		Total		Tail		Head and Body	
		mm.	in.	mm.	in.	mm.	in.
37768	Male	169	6.65	29	1.14	140	5.51
37769	Male	185	7.28	27	1.06	158	6.22
37770	Male	196	7.74	32	1.26	164	6.48
37772	Female	181	7.12	27	1.06	154	6.06
37773	Male	184	7.24	34	1.34	150	5.90
37774	Male	190	7.50	30	1.18	160	6.32
37775	Male	178	7.00	28	1.10	150	5.90
37776	Female	185	7.28	29	1.14	156	6.14
37777	Female	176	6.94	33	1.30	143	5.64
37778	Male	172	6.78	30	1.18	142	5.60
37779	Male	181	7.13	38	1.50	143	5.64
37780	Male	184	7.24	34	1.34	150	5.90
37798	Female	216	8.50	36	1.42	180	7.08
Averages		184	7.24	31	1.22	153	5.98

MEASUREMENTS OF SPECIMENS FROM VARIOUS LOCALITIES WITHIN THE STATE

Acc. No.	Locality	Sex	Length					
			Total		Tail		Head and Body	
			mm.	in.	mm.	in.	mm.	in.
37758	Exact locality unknown	Female	172	6.78	24	.94	148	5.84
37759	Normal	Male	190	7.50	37	1.46	153	6.04
37760	Exact locality unknown	Male	182	7.17	34	1.34	148	5.83
37763	Exact locality unknown	Female	172	6.78	27	1.06	145	5.71
37764	Exact locality unknown	Female	171	6.74	30	1.34	141	5.40
37765	Normal	Female	170	6.70	27	1.06	143	5.64
37894	White Heath	Female	181	7.13	36	1.42	145	5.71
38242	Quiver Tp.	Female	164	6.48	25	.98	139	5.50
39604	Flora	Male	190	7.50	37	1.46	153	6.04
Averages			177	6.98	31	1.22	146	5.71

Combining all the above individual measurements, we obtain the following average for all of our forty-nine specimens from the state: total length, 181 mm. (7.13 in.); length of tail, 32 mm. (1.26 in.); length of head and body, 148 mm. (5.83 in.). The proportion of the specimens of the various lengths is indicated by the accompanying frequency polygon.

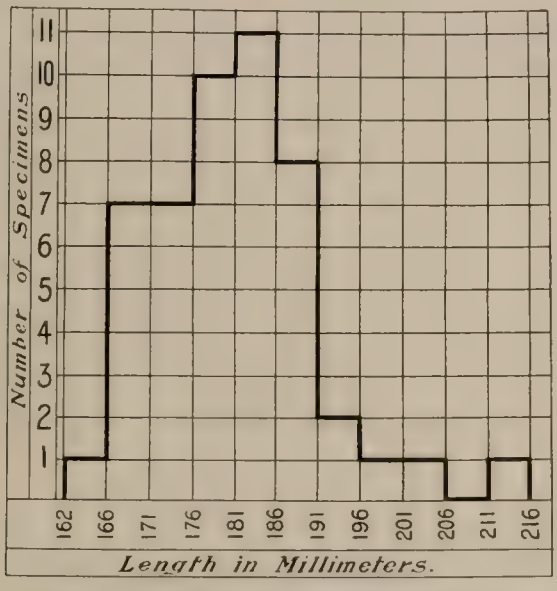

FIG. 1. POLYGON OF LENGTHS OF FORTY-NINE INDIVIDUALS OF THE COMMON MOLE.

There is also considerable individual variation in color, not correlated with any other evident characteristic, or with peculiarities of habitat, so far as I have been able to make out. The fur, except on the snout and extremities, is dense, fine, and silky, with but very little slope, so that it offers little resistance to rubbing in any direction. The hairs on the back attain a length of 1 cm. (.39 inch) or more, becoming shorter on the under parts.

The general color corresponds to that called "hair-brown" in Ridgway's nomenclature. This is sometimes grayish, sometimes warmed to bister or sepia, and is always obscured by a shifting, sheeny luster. Closer examination shows that the basal four-fifths of each hair is kinky, and is plumbeous in color, while the distal fifth is straight and bent at an angle to the general direction of the main portion. The direction of this tip constitutes the greater part of whatever slope there is to the hair. Under a low power of microscope it will be found that the hairs are flattened, and that the color of the basal portion is due to alternate black and translucent bands, while the apex is broader, lanceolate in shape, and contains a core of brownish-orange coloring matter. The chin, throat, upper surface of fore paws, and wrists are much lighter, and often suffused with shades varying from ochraceous to ferruginous, or even, in spots, to a decided orange. The tail is whitish at base, nearly naked and pinkish at the tip, as is also the tip of the snout and the toes. Specimens taken in spring often show patches of new fur replacing the old, and the fur in these patches is shorter and darker than the old fur. The snout is prolonged about 8 mm. beyond the lower jaw. It is flattened and deeply grooved below, and is naked and truncate at the apex at an angle of 45 degrees. This truncated surface looks upwards and contains the nostrils. At the tip is a hard nail-like body. The upper lip is split and represented by two thin folds in front. The long snout of the mole is very flexible, and is in constant motion when the animal is in action. It is abundantly supplied with nerves and terminal sense organs. The sense of smell and the sense of touch in the snout must be, for the mole, the chief means of an acquaintance with the outside world.

The fore limbs are concealed to the wrist under the skin. The fore paws are enormously developed. The toes, five in number, are webbed their whole length, making the entire length of the palm 15 to 20 mm. (.6 to .8 in.). The width is still greater, being 20 to

25 mm. (.8 to 1 in.). This great width is produced by a flap of skin on the lower edge, the rigidity of which is maintained by an extra sickle-shaped bone. The palm is margined with stiff hairs. The nails are stout, flattened, semicylindrical, and translucent enough to show the bifid tips of the last finger bones within. The hind feet are of normal size, five-toed, with nails that are flattened, hollowed below, and rather slender. The tail is squarish, especially at the base.

The general impression given by the appearance of the arms and shoulders of a mole stripped of its skin and superficial fat is that of a wonderfully compact and powerful digging machine, to which the animal is strapped by comparatively slender muscular bands. The development of the muscles of the breast and shoulders has kept pace with the massiveness of the bones. The pectoral muscles are attached to a keel-like projection of the sternum, and by their thickness remind one of the breast of a bird. Certain muscles of the shoulder are also greatly developed, and in some of them it seems that muscular overgrowth has reached its limit.

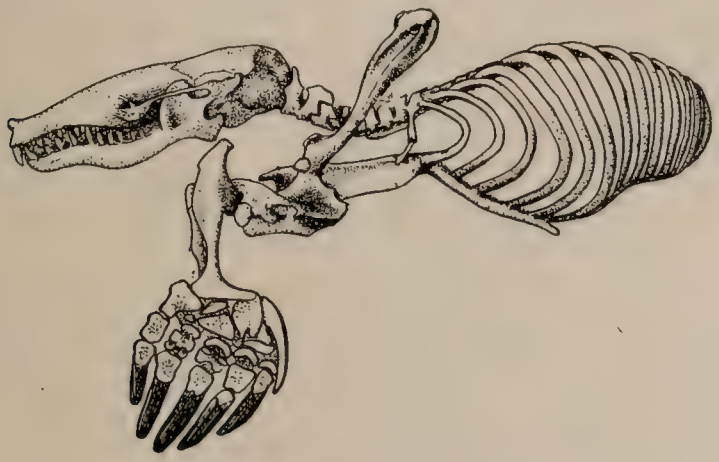

FIG. 2. PART OF SKELETON OF MOLE, SHOWING ATTACHMENT OF FORE LEGS.

The thick fur hides the eye and ear, but they may be located if the hair is cut off close. The eye appears as a protuberance, about the size of a pinhead, 20 to 25 mm. (.8 to 1 in.) from the end of the snout. If the skin at that place is lifted up, the eye will be found

on the under side—a black speck between the skin and the skin muscles. It is not within the bony orbit of the skull, but outside and in front of it. Microscopic examination reveals an opening through the skin over the eye, but it is difficult to find without a lens. The eye itself, though containing rudiments of the essential parts of the normal mammalian eye, is so degenerate that distinct vision is impossible, and at most it can only serve to distinguish light from darkness.

Owing to the fact that the shoulder bones and the attachment of the fore limbs are so far forward of the usual position, the external opening of the ear appears to be on the shoulder, though in reality it is not misplaced with reference to the skull. There is no true pinna or external ear, but the external auditory meatus is prolonged beyond the head a few millimeters by a cartilaginous tube. Between the eye and the ear is a protuberance containing vibrissæ, and probably functioning as an organ of touch.

The mole has thirty-six teeth. In each upper jaw there are three incisors, one canine, three premolars, and three molars. In the lower jaw there are two incisors, no canine, three premolars, and three molars. The two middle incisors in the upper jaw are large and seem to resemble those of the rat and other rodents at first sight, but they differ greatly in structure, having enamel on all sides, instead of only in front like the rodents. The second and third incisors are small and often missing. In the lower jaw the middle incisors are small and the lateral ones of moderate size. The molars and premolars form very irregular surfaces, the projections of the lower teeth fiting into corresponding hollows in the upper teeth, and vice versa. This construction of the teeth and the strictly up-and-down motion of the jaws are well adapted to the chopping up of insects or other animal food, but do not permit any grinding motion as is the case with animals living on seeds, grain, or other vegetable food. On account of this structure of the teeth naturalists have been loath to believe that the mole ever eats vegetable food, for which its teeth seem so ill adapted.

Although the shrew-mole ranges throughout the state, there are certain sections where it is rare or unknown. In most cases the cause for this is not far to seek. Moles require a soil easily penetrated by their burrows and containing an abundance of worms or insects for their food. Evidently a soft, rich loam, not too thoroughly cultivated, is their ideal habitat, and such localities usually contain an abundance of them. Stony or coarse gravelly soils are avoided, but

they are found in light sandy soils where ease of burrowing compensates for the poorness of the subterranean fauna. They are in no sense aquatic, so far as has been observed in this state. They may be tempted, by an abundance of food, to run their burrows into low ground, even into tracts submerged during parts of the year, but almost invariably such runs will be found to communicate with others furnishing a retreat to higher ground. Burrows are often seen running down the bank of a stream or across the muddy shore of a pool, nearly or quite to the water's edge; but I have never seen a fresh opening under the water or, indeed, quite reaching it, except where there had been a recent decided rise of the water-level. Undoubtedly, like most mammals, moles can swim, but I doubt if our form ever habitually enters the water for food.

The species has been taken, or reported on reliable authority, in the following places within the state.

Place	County	Authority
Chicago	Cook	Field Museum
Hanover	Jo Daviess	F. C. Gates
Milan	Rock Island	H. A. Gleason
Warsaw	Hancock	F. W. True: Revision of American Moles
Hamilton	Hancock	F. W. True: Revision of American Moles
Quincy	Adams	J. A. West
Brussels	Calhoun	J. A. West
Galesburg	Knox	J. A. West
Quiver Tp.	Mason	State Laboratory
Normal	McLean	State Laboratory
Bloomington	McLean	J. A. West
Havana	Mason	State Laboratory observation
Decatur	Macon	J. A. West
Atlanta	Logan	J. A. West
Lincoln	Logan	J. A. West
Mt. Pulaski	Logan	J. A. West
White Heath	Piatt	State Laboratory
Monticello	Piatt	State Laboratory
Virginia	Cass	F. C. Gates
Many localities	Champaign	State Laboratory
Danville	Vermilion	J. A. West
Jacksonville	Morgan	State Laboratory
Alton	Madison	Spencer F. Baird: Mammals of North America
Belleville	St. Clair	F. W. True: Revision of American Moles
Mascoutah	St. Clair	C. F. Hottes
Windsor	Shelby	H. A. Gleason
Charleston	Coles	T. L. Hankinson
Odin	Marion	J. A. West
Murphysboro	Jackson	J. A. West
Flora	Clay	A. O. Gross
Carbondale	Jackson	J. A. West
Marion	Williamson	J. A. West
Olive Branch	Alexander	State Laboratory observation

During a week's collecting in the vicinity of McHenry, in McHenry county, not a trace of a mole or of mole work was seen, and apparently the farmers were quite unacquainted with either. More recently, however, the presence of moles in that town has been reported. Probably there are other sections of the state in which they are rare or lacking, but we have no authentic record of such.

The burrows of the mole are almost always excavated, not by bringing the dirt to the surface, but by pushing it aside. The method seems to be as follows: The head is lowered and retracted—the flexibility of the neck permitting this—the fore paws are thrust forward in front of the nostrils, and by a sort of swimming motion the earth is pushed aside, the head at the same time being advanced and raised. The flexible snout is kept in continual motion, probably for exploring rather than for loosening the soil, as was once thought. The mounds of dirt thrown out are usually from burrows moderately deep. Presumably this is done only when the animal finds it difficult to dispose of the dirt otherwise. However, in central Illinois, I have never been able to correlate the presence or absence of such mounds with hardness of the soil. Possibly they are rather an indication of the depth of the excavations. When present they are in general at the top of vertical shafts ascending, not directly from the main tunnel, but from a short lateral one. How the earth is brought to the surface is not known.

Audubon and Bachman, in their great work on the quadrupeds of North America, mention the finding of two nests with young, one containing five and the other nine, and this observation seems to be the sole basis for all statements on this point made by most writers since. Kennicott's informant who reported a gravid female in February with two young "clothed with hair" and about to be brought forth must have made some mistake. There are four young moles in the Laboratory collection averaging over 100 mm. in length, but they are still nearly hairless. The result of an examination of all females in our collection accompanied with data of capture is shown in the table on page 9.

These observations seem to indicate one litter a year, brought forth in the latter part of April or early in May. All data available for this state suggest that the average number in a litter is nearer three to six than "from five to nine." In No. 38347 all six of the teats bore evidence of being used.

RESULTS OF EXAMINATION OF FEMALE MOLES IN THE LABORATORY

Acc. No.	Date of Capture	Condition
37984	April 4, 1908	Uterus large; empty
37985	" 16, "	3 embryos, 45 mm. long
37986	" 17, "	3 embryos, 15 mm. long
37347	May 23, "	Uterus medium size; empty; mammæ very large
37798	" 30, 1907	" small; empty
38348	June 1, 1908	" empty, but of considerable size
38349	" 1, "	" small; empty
38350	" 2, "	" " "
38352	" 3, "	" " "
38353	" 4, "	" large, but empty
38355	" 9, "	" small and empty
38356	" 10, "	" shrunken and empty
38357	" 10, "	" much shrunken
38366	" 13, "	" " "
38367	" 13, "	" " "
38368	" 15, "	" " "
38369	" 16, "	" " "
38376	" 17, "	" " "
38235	October 26, 1908	" very much shrunken

The economic relation of the mole—whether beneficial or injurious—has been a disputed topic for many years. It could not be denied that the burrowing habit of the mole is an annoyance and indeed a positive injury to lawns, cemeteries, etc., but besides this mechanical and incidental injury, gardeners and farmers have maintained that moles do a more definite and deliberate damage by eating newly planted seeds, by following along the rows of corn, peas, etc., taking all the seeds from hill after hill in succession, and by eating parts of plants, the roots of vegetables, the tubers of potatoes, and the like. On the contrary, naturalists in general, reasoning from the anatomy of the animal, the structure of its teeth, and the proven fact that it feeds largely on insects, worms, and other underground animals, have doubted the possibility of its eating vegetation to any great extent, and have accounted for the injury to seeds and vegetables commonly charged to moles as really due either to insects which the mole itself was seeking, or to mice which entered the mole's burrow after it.

In this state the most bitter complaint against moles has been that they destroy recently planted corn. In some cases it was said that 25 per cent. of the first planting of a field had been destroyed. In the spring of 1907, when the writer was serving as a zoological as-

sistant in the State Laboratory of Natural History, a reported injury to corn by moles was assigned to him by Dr. Forbes for investigation. The field work was chiefly done in the vicinity of Jacksonville, Illinois, during corn-planting time and while the grain was beginning to grow. Extensive trapping was done in corn fields, gardens, and various neighboring fields, including pastures, fallow ground, and woodland. Corn was put in the burrows to see if the moles would eat it. Moles were said by farmers where we worked to be much less common than usual, but a number were caught and their stomachs were preserved for examination.

The injury done was limited chiefly to the edge of the field, mostly within fifty feet and virtually all within a hundred feet of the margin. Moreover, it was much greater in those parts of the field next an old hedge, a woodland, or pasture, or any uncultivated land, where, of course, the tunnels of the moles were undisturbed. Very little damage was done in the interior of large fields. Although moles work in corn fields all summer and fall, yet, so far as my observations go, the damage is practically all done within the first ten days after planting, and by far the most of it within the first five days. During this time the moles enter the field by burrows branching off from their permanent runs along the hedges or in the adjoining uncultivated fields, and spread out among the newly planted corn rows. These runs in the freshly planted field tend to follow the rows of corn in the direction in which the planter was driven, and not along the rows checked off by the chain. Tunnels entering at right angles to the direction of planting soon turn and follow that direction. Approximately 75 per cent. of the burrows made during the first few days after planting were directly in the furrow made by the planter. The remaining 25 per cent. were divided about equally between two courses, those parallel to the rows but not entering them, and those making various angles with them.

As an illustration of the extent and nature of the damage done, the following rather extreme case may be given. Three adjoining rows, the farthest within thirty feet of the edge of the field, had been entered from that side. In the first row the line of hills had been followed for one hundred and twenty feet, and there were only three or four hills uninjured within that distance. In the second row all hills had been taken for thirty feet, and in the third row all were missing for seventy-five feet. These burrows following the rows and

those connecting them with the edge of the field were nearly all the burrows in that immediate locality. Wherever a burrow passed through a hill, the corn was missing. The three or four hills still growing in the one hundred and twenty-foot distance mentioned above, had been missed by the burrows, which passed around and not through them. This corn had been planted about a week. In an adjoining field planted twelve days before, there were also extensive mole-runs, all made after a recent rain. Here the burrows ran irregularly in all directions, no preference being shown for the direction of the rows. No damage had been done by these freshly made burrows in the first-planted field, though the mole had sometimes lifted young plants by burrowing under the hills. It is possible that if the weather had been hot and dry the corn in these hills might have withered. Farmers, indeed, maintain that this is sometimes the case. This observation of the work of moles in corn fields was continued throughout the season in various parts of the state until December. In midsummer the moles burrowed to a depth of about six inches, but did not tend to follow the rows, nor was any injury done to the corn except possibly a trifling one due to undermining the plants. Peas and beans planted by drills in gardens were sometimes injured in the same way as corn in the field, but here too the injury was done during the first week after planting, and the later burrows did not tend to follow the direction of the drills.

On visiting a badly infested corn field it is easy to understand how an uncritical observer might attribute to the mole a deliberate malice and a cunning almost human in finding and destroying the newly planted corn, but probably a simpler explanation of the facts may be given. In soft ground the runs of the mole are often carried for long distances in a straight line. I have seen such runs several hundred feet long in the sandy fields of Mason county. Probably the course of the drill of the planter is followed because it offers the line of least resistance immediately after planting. Later, when the ground becomes settled, so that all parts of the soil are equally firm, there is no apparent choice in the direction of the runs.

It has been suggested in defense of the mole that grubs or other insects may destroy the germinating corn, and that the mole visits the hills to capture the insects. If this be so, the mole is certainly a marvelously effective agent for the destruction of insects, for often not a hill of corn will be missing out of many acres except where

there is a mole-run. It has been also said that field-mice may enter the runways of the mole, and that they and not the moles may eat the seed grain. Field-mice doubtless make use of old mole-runs, but would scarcely enter such a run while its owner was still present; and as the seed is eaten and the plants are destroyed at the time when the burrows are dug, the injury cannot be attributed to anything else than the mole.

Moles are accused not only of destroying recently planted seed, but also of eating the roots or tubers of garden vegetables. Late in the season of 1907 I visited a field at White Heath, in which it was said that much damage had been done by moles. The potatoes had been dug just before my arrival but partly eaten tubers were abundant, all near the edge of the field, and next to woodland and pasture. The moles had tunneled extensively among the potato hills, and many of the potatoes had been eaten by them, as appeared plainly from the marks of incisor teeth, which just fitted the teeth of the mole, but were much too broad to be the work of the mice or voles found in the vicinity. Chipmunks and gophers were in the adjoining fields, but of course would have taken the potatoes, if at all, by digging down into the hills and not by an underground tunnel. The loss in parts of the field was some 25 per cent. During the past season the same field was planted to potatoes again. I visited it in September, before the potatoes were harvested. Mole-runs were numerous in the field, running among the rows in all directions, but in no definite relation to the hills. Tubers had often been laid bare by the moles but they were generally uninjured. A few had been eaten by grubs, but only one by a mammal. Evidently the moles, while not searching for vegetable food, do sometimes avail themeslves of it when it is present. Usually their tunnels are so placed that little vegetable matter is encountered in making them—too small an amount to supply any considerable part of the energy expended by this powerful and active animal. The injury done by moles to lawns and other grass-lands is undoubtedly done in their search for insects and worms. It is not, indeed, great except in small lawns, cemetery lots, and the like, the appearance of which they may injure sufficiently to call for their destruction.

But little is known definitely in regard to the enemies of moles. Cats and dogs kill but do not eat them. Weasels, skunks, and foxes probably kill them occasionally and, when hard pressed for food, may

eat them. In Dr. Fisher's study of the contents of 2645 stomachs of birds of prey, moles were found only four or five times. ("Hawks and Owls of the United States".) There seems to be a considerable local variation in the numbers of moles from year to year, and they are often found lying dead, but unmutilated, above ground in considerable numbers. Many of them are badly infested with intestinal parasites, which possibly tend to reduce their numbers. Two such parasites, specimens of *Filaria* and *Spiroptera,* were abundant in the stomach and intestines of many of the moles collected by us for a study of their food.

My own attempts to poison moles have had uncertain success, as it was difficult to tell, even approximately, the number killed. They eat bits of raw beef readily in captivity, and might be poisoned by putting strychnine on bits of meat and placing these in their runs. I have found trapping the best way to destroy them. A single mole will do a surprising amount of burrowing in a week, and the number of moles doing noticeable damage in any locality is generally not large. It is difficult to trap them in midsummer, when they frequent only their deeper burrows, but easy in spring or autumn, when they work near the surface. There are a number of good mole-traps on the market, all made with reference to the mole's habit of persistently repairing a burrow if its roof is broken in. Where the work of the mole is evidently recent, a virtual extermination by trapping is neither difficult nor tedious. Even in places where they have been long established, and where the ground may not be plowed up, persistent work during the spring months will accomplish much. Where there is an intricate network of old runs it is very difficult to trap them; yet even here occupied runs may sometimes be detected. If the trap is undisturbed for twenty-four hours it may be safely inferred that it has been placed on an abandoned runway, and another trial must be made elsewhere. During the season of 1908 experiments were made by treating seed-corn with kerosene, carbolic acid, formalin, oil of lemon, and other vegetable oils, to see whether moles would be so repelled by these substances that they would not disturb the corn. No definite results were obtained, however, except where an amount of repellent was used sufficient to injure the seed.

October, 1910.

ARTICLE II.—*A Study of the Food of Moles in Illinois.* BY JAMES A. WEST.

The moles which furnished the basis for this discussion were in part specimens collected in central Illinois at various times, whose stomachs had been preserved with the material of the State Laboratory of Natural History without definite data as to the special situation in which the moles were found, but chiefly specimens recently collected, nearly all trapped in 1907 and 1908 by Mr. F. E. Wood, assistant in the State Laboratory of Natural History.

In April, 1907, special interest in the subject of the feeding habits of the mole was stimulated by a letter from C. A. Rowe, of Jacksonville, Illinois, to Dr. S. A. Forbes, Director of the State Laboratory, under whose direction this investigation was undertaken. Mr. Rowe reported that moles had been very abundant in that locality for several seasons, and that they had been seriously destructive to seed-corn in recently planted fields. His letter was accompanied by the contents of a mole's stomach, which proved to be about 65 per cent. corn.

On account of the subterranean life of the mole its feeding habits are but little known. In captivity it is a voracious feeder, incapable of enduring any considerable period of starvation. The only accurate way, however, of determining the character of its natural food is to examine the material which it has actually eaten.

METHOD OF EXAMINATION

In studying the food of the mole we must examine and classify in detail the entire stomach contents of each specimen, and must estimate the amount of each of the food materials, taking account also of any undetermined residue. For this purpose sheets of filter-paper, twenty by twenty inches, were ruled into one-inch squares and placed on a sheet of glass. A stomach was then opened and the contents, put into a dish with alcohol, were broken up by agitation and thrown upon the filter-paper in a way to distribute the particles of food well over it. The material on each square was then examined and estimated separately. If the entire stomach content, or the greater part of it, was composed of one material—earthworms, for example—it was often possible to determine its character by simple inspection.

The contents of the stomachs examined were mainly earthworms, insects—either adults, larvæ, or pupæ—vegetation, and a miscellaneous remainder. The mole had commonly chewed its food so fine as to make it impossible to recognize the species of insects and their larvæ; nevertheless, the number specifically determined was sufficient to give a fair idea of the dominant character of the insect food.

GENERAL RESULTS OF THE EXAMINATION

The following table shows the per cent. of the various kinds of food in each stomach. There is no "miscellaneous" column, since stomach contents not otherwise assignable were rare, and may conveniently be mentioned later.

Accessions Number	Per cent.				Collection Data
	Earthworms	Adult Insects	Insect Larvæ	Vegetation	
1	10		90		
2	20	70	5	5	
3	60	20			
4	45	15	10	30	
5	25	5	70		
6		100			Urbana, Jan. 26, 1887. Well
7	60	10	30		Normal, April 17, 1883
8	75	10	10	5	Normal, April 19, 1883
9	45	20	35		Normal, 1887
10	30	10	30	30	Normal, 1877
11		20	10	70	Normal, July 29, 1884
12	55	15	30		Urbana, March 26, 1886
13			35	65	Jacksonville, April 20, 1907. Yard

Accessions Number	Per cent.				Collection Data
	Earthworms	Adult Insects	Insect Larvæ	Vegetation	
14	80	5	13	2	Jacksonville, May 21, 1907. Plowed field
15		95	5		Jacksonville, May 22, 1907. Woodland
16	5	10	55	30	Jacksonville, May 23, 1907. Garden
17	80		20		Jacksonville, May 23, 1907. Plowed field
18		40	60		Jacksonville, May 24, 1907. Garden
19	100				Jacksonville, May 24, 1907. Garden
20		80	15	5	Jacksonville, May 24, 1907. Plowed field
21	30	20	20	30	Jacksonville, May 24, 1907. Corn field
22			95	5	Jacksonville, May 24, 1907. Corn field
23	50	40		10	Jacksonville, May 25, 1907. Corn field
24	35	5	60		Jacksonville, May 26, 1907. Garden
25		5	75	20	Jacksonville, May 27, 1907. Garden
26	40		45	15	Jacksonville, May 27, 1907. Yard
27	10	85	5		Jacksonville, May 27, 1907. Woodland
28	15	5	70	10	Urbana, June 29, 1907. Woodland
29		50	25	25	White Heath, Oct. 17, 1907. Corn field; corn cut and shocked
30		5	5	90	White Heath, Oct. 17, 1907. Corn field; corn cut and shocked
31	75	5	20		Staley, Oct. 26, 1907. Sod
32		80	20		Topeka, October 30, 1907. Corn field
33		65	35		Urbana, April 4, 1908. Dooryard
34	100				Urbana, April 17, 1908. Woods

Accessions Number	Per cent.				Collection Data
	Earthworms	Adult Insects	Insect Larvæ	Vegetation	
35	30	25	40	5	Urbana, May, 15, 1908. Cemetery
36	20	20	25	35	Urbana, May 22, 1908. Cemetery
37	15	20	60		Urbana, May 28, 1908. Cemetery
38		15	65	20	Urbana, June 1, 1908. Corn field
39			80	20	Urbana, June 1, 1908. Cemetery
40		10	90		Urbana, June 2, 1908. Cemetery
41	30	25	40	5	Urbana, June 2, 1908. Cemetery
42		40		60	Urbana, June 3, 1908. Corn field
43			95	5	Urbana, June 4, 1908. Edge of corn near pasture
44			85	15	Urbana, June 4, 1908. Corn field
45	90		10		Urbana, June 9, 1908. Alfalfa
46			90	10	Urbana, June 10, 1908. Alfalfa
47		100			Urbana, June 10, 1908. Cemetery
48		100			Urbana, June 12, 1908. Cemetery
49	15	5	45	35	Urbana, June 12, 1908. Corn field
50	70	20	10		Urbana, June 13, 1908. Cemetery
51			100		Urbana, June 15, 1908. Alfalfa
52		60	40		Urbana, June 16, 1908. Clover
53		5	95		Urbana, June 17, 1908. Clover
54	30	40	30		Urbana, June 17, 1908. Clover
55	95			5	Urbana, June 18, 1908. Clover
56		80	20		Flora, Aug. 25, 1908. Orchard

The preceding table shows that 31 moles had eaten earthworms, which formed 26 per cent. of the total food of the 56 specimens; 53 had eaten insects, amounting to 62 per cent. of the total food, of which 36 per cent. was insect larvæ (contained in 47 stomachs), and 26 per cent. was adult insects (in 42 stomachs). The 3 moles which had eaten no insect food had taken earthworms, and one of them a little grass. Vegetable matter was present in 28, to the amount of 11 per cent. of the total food. About 1 per cent. of the stomach contents are classed as miscellaneous. This includes spiders, myriapods, needles from a spruce tree, mole hair, and feathers, these various items each occurring but once, except spiders, which were found twice.

Before entering into further details it seems desirable to add a table giving a summary exhibit of the situations where the fifty-six moles were taken, the number from each situation, and the number of occurrences of the different kinds of food, classified in relation to situation. The table, page 19, although very imperfect, may serve a useful purpose to those pursuing the subject later.

DETAILS OF THE FOOD.

Such kinds of their food as are quite generally distributed—earthworms, some insect larvæ, and adult insects, for example—are very frequently and freely eaten by moles. This is evident in the case of earthworms, white-grubs (larvæ of *Lachnosterna* and *Cyclocephala*), cutworms, wireworms, ground-beetles and their larvæ, and the common brown ant. Fragments of at least 9 white-grubs were present in one stomach; and the bronzed, the W-marked, the glassy, and the dingy cutworms were all identified. Among *Carabidæ*, the following genera were distinguished: *Pterostichus, Agonoderus, Bembidium, Harpalus, Platynus,* and *Geopinus*. *Geopinus incrassatus* had been eaten by a mole in the sand region near Havana, Illinois, where this insect is quite abundant. Other larvæ prominent in the food were sod web-worms and larvæ of the banded Ips, each occurring twice. One mole had eaten at least 18 sod web-worms, and another at least 85 larvæ of *Ips quadriguttatus*. May-beetles had been eaten only by moles living in sod in the months of May and June. Whenever present they formed a large part of the contents, and one stomach contained nothing else. The common corn-field ant, *Lasius niger americanus*, was present in several stomachs in large numbers. The single mole taken in winter (January) had eaten no less

Kinds of situations in which moles were taken	Number of moles from each situation	Various items of food and number of stomachs in which each item was found														
		White-grubs	Cutworms	Wireworms	Carabid larvæ	Sod web-worm	Nitidulid larvæ	Carabid beetles	June-beetles	Elaterid beetles	*Lasius niger americanus*	*Camponotus*	*Solenopsis*	*Myrmica*	Corn	Vegetation	Earthworms
Sod	14	4	4	3				5	5		1				2	4	7
Unknown	12	5	1	1	4	1		6		2	4				1	4	10
Corn field	11	5	2	2	2	1	2	4			1			1	7	2	3
Garden	5	2	3	1				1				1			1	1	3
Woodland	4							2				4				1	3
Clover	4		2					3		2	2					1	2
Alfalfa	3	1	2	1												1	1
Plowed ground; not planted	3		2	1							1		2			1	2
Totals	56	17	16	9	6	2	2	21	5	4	9	5	2	1	11	15	31

than 150 specimens of this ant. The carpenter-ant, *Camponotus pennsylvanicus,* which usually nests in logs and stumps in shady woods, was found in the stomachs of all moles taken in woodlands and in one from a garden. Two more species of ants were recognized: *Solenopsis debilis,* present in two moles taken in plowed ground; and a *Myrmica,* probably *scabrinodis,* which was found in a single mole captured in a corn field. The click-beetles shown in the table formed but a small part of the total food, and but one buprestid was found. The abdomen of a wasp very much like that of *Tiphia* was found in a mole from a corn field, and a hymenopterous puparia had been eaten by one from an alfalfa field. Two noctuid pupæ occurred in the stomach of a mole from a corn field. It is unfortunate that an important part of the insect food must remain unclassified.

Corn was present in the stomachs of eleven moles, making 8 of the 11 per cent. of vegetable matter eaten by them. Five of these specimens were trapped in corn fields in spring, shortly after corn had been planted, and three of the five had burrowed along the planter track. Two were taken from fields in which the corn was cut and shocked, two were from lawns, and one was from a garden, corn being near at hand in each case. Indeed, corn had been carried into the run of one of the moles trapped in the lawn. Corn in some cases formed the principal part of the stomach content, in one instance 90 per cent. Six moles which probably had access to corn, had eaten none.

Some observations made in the spring of 1908 on the work of moles in corn fields illustrate the nature of the damage they may do. In one instance the writer saw a mole-run which followed the track made by a planter wheel for a distance of seventeen hills. Occasionally the mole had turned slightly out of its course; but it had immediately worked back into the packed soil. The corn had sprouted and was showing above ground. Fourteen hills in this strip were dead or dying, the kernel having been eaten away and the sprout left untouched. A similar instance is reported of eighteen hills, not all in the same row, destroyed, apparently by a single mole, after the corn had sprouted. In another case one or more moles, entering a corn field from a pasture adjoining, formed a network of burrows in an area ten hills wide by nineteen long. Eighty-nine corn hills were missing in this plot. Grass, grass-roots, seeds, etc., were frequently found in the mole stomachs, usually in small quantities, but

amounting in three cases to 30 per cent., and in one to 35 per cent. of the food.

The known dates of capture of the moles were as follows: January 1, March 1, April 5, May 17, June 19, July 1, August 1, and October 4. Seven of the fifty-six specimens were preserved without dates.

Twenty-eight of the stomachs were well filled with food, 21 were moderately filled, and in 7 there was but a small amount.

CONCLUSIONS OF OTHER WRITERS

In the Seventh Report of the Kentucky Agricultural Experiment Station (1894) H. Garman reports the examination of fourteen mole stomachs. He found some fragments of dead parts of grasses and other plants, taken, as he believes, by accident while animal food was being devoured, but no traces of fresh plant structures. He says: "I am disposed to acquit the mole of the charge of intentionally eating vegetation. I do not offer this as a final conclusion, however; more material should be studied."

Fifty stomachs containing food were examined by L. L. Dyche, as reported in Volume XVIII of the Transactions of the Kansas Academy of Science. He says that vegetable food, almost all of it corn, amounted to 3.7 per cent. of the whole. Corn was found in 4 stomachs, in the ratios of 10, 30, 60, and 65 per cent. of the food of these animals, respectively. The last two were taken in January and October. "It is evident," he says, "that the damage done to lawns, gardens, and fields by moles is due chiefly, not to the food the animals eat, but rather to their manner of securing it."

Another paper on this subject is published in Bulletin No. 31 of the Pennsylvania Department of Agriculture. Of 36 stomachs, examined by Harry Wilson, only one contained green tissue of grain, but this had been bitten off in pieces by the teeth of the mole. One mole, killed in the ground under a corn shock, contained corn about equivalent to a single kernel. Wilson believes that all the damage done by the eating of grains, seeds, and fibrous roots, and by the gnawing of tubers, which is attributed to moles is due to mice, for it is a fact, he says, that the runways of the mole are often occupied during the latter part of the summer by the common brown field- or meadow-mouse.

CONCLUSION

The contents of the stomachs here reported, have shown perhaps a greater amount of insect food and somewhat smaller ratios of earthworms than those examined by other writers, but there is a substantial agreement to the effect that half or more of the food of the mole consists of insects and their larvæ, most of them noxious. So far as its food is concerned, the mole is thus beneficial, on the whole. There is no direct evidence that it will eat potatoes or other tubers, but circumstantial evidence on this point is so strong that the mole must remain under suspicion, even admitting that mice of herbivorous habit may occupy mole-runs in fall. In this paper it is shown, for the first time, that corn may form an important item of the food of moles; that recently planted corn is sometimes destroyed by them; and that if numerous in corn fields in spring, they are capable of doing considerable damage there.

October, 1910.

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OF THE

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URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. OCTOBER, 1910 ARTICLE III.

THE VEGETATION OF THE INLAND SAND DEPOSITS OF ILLINOIS

BY

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ARTICLE III.—*The Vegetation of the Inland Sand Deposits of Illinois.* By HENRY ALLAN GLEASON.

INTRODUCTION*

In the rapid development of ecological and phytogeographical knowledge during the past few decades, the vegetation of sand deposits has been the subject of especially frequent and detailed study. At least three reasons may be mentioned why this type of vegetation has received particular attention. First, sand deposits are usually well developed and form dune complexes of greater or less extent along the shores of the ocean or the larger inland lakes, and in many cases are convenient places for vacation trips. Secondly, the vegetation on sand is usually open and easily studied, and the dynamic nature of the environment is emphasized. For this reason the interrelations of plant and environment are more easily observed and offer attractive fields for study. Thirdly, sand areas are usually infertile in comparison with their surroundings. They are accordingly frequently left uncultivated and constitute temporary natural preserves, in which the original types of vegetation persist and are available for study.

In the case of the inland sand regions of Illinois the first statement is hardly effective, and that may explain why they have received relatively little attention from local botanists. At the present time, however, they comprise the largest, and virtually the only, areas of natural vegetation within the state. With the exception of parts of the sand deposits, of some small swamp areas, of rock outcrops, of ponds and lakes, and of some small tracts of forest, all the original vegetation of Illinois has been destroyed or greatly modified by clearing, planting, or pasturing. The area covered by the last four of these exceptions is very small, but there are still thousands of acres of sand deposits in nearly original condition and available for study They still contain some virgin prairie that has never been plowed or pastured. These prairies are probably somewhat different from the more representative types of prairie which formerly grew upon more fertile soil, but they are much more nearly typical than the small strips still occurring along the margins of some streams and ponds.

*The field work upon which this article is based, was carried on by the aid of a grant from the Botanical Society of America. Further financial assistance was given by the Illinois State Laboratory of Natural History.

The study of the vegetation of the sand deposits of Illinois is therefore of especial scientific interest because they constitute the only considerable area of natural vegetation in the state, and because their vegetation is closely related to that of the original prairie. It is also of some general value, since it concerns an area which has received little attention from botanists, and because it affords intelligible illustrations of certain ecological principles.

The field work upon which the present paper is based was done during the summer of 1908. Reference is also frequently made to the field work at Havana in August, 1903, and August, 1904, the results of which have already been published (Hart and Gleason, *1907*). The itinerary during 1908 was as follows:

May 28, 29, St. Anne, Kankakee county.

May 31-June 3, June 12-24, August 15-18, Hanover, Jo Daviess county.

June 25-29, Shirland, Winnebago county.

June 30-July 3, August 19, 20, Dixon, Lee county.

July 4-15, August 10-14, Oquawka, Henderson county.

July 16, Forest City, Mason county.

August 7, Topeka, Mason county.

August 8, Havana, Mason county.

August 21, Amboy, Lee county.

From June 12 to 19 Mr. Frank C. Gates assisted in the field work. He also identified many of the plants mentioned in the paper. The grasses and sedges were identified through the courtesy of Mrs. Agnes Chase. Mr. H. N. Patterson rendered important assistance in the field work in the Oquawka area. Dr. H. S. Pepoon has supplied valuable information concerning the Hanover area. To each of these the writer extends his thanks for their interest and appreciation.

The photographs have been taken by the writer, using a folding film camera, Ansco films, and tank development.

Physiography and Origin

The chief sand deposits of Illinois lie in the northern half of the state, between latitude 40° and 42° 30′. In the southern half sand occurs only in small local deposits or in bars near the larger rivers, and is never of such extent that a peculiar vegetation is developed upon it. Banks and bars of sand also border the streams of northern Illinois, but their vegetation bears little relation to that of the larger deposits here described.

For convenience the sand areas have been given names taken from

some geographical feature of the vicinity. Some of these areas are contiguous, and some owe their existence to the same causes. The names, therefore, do not indicate areas which are geologically distinct, but merely general locations in which the field work was prosecuted. The geography of each of these regions will be described separately.

The Havana Area.—The Tazewell sheet of the Field Operations of the Bureau of Soils (Bonsteel, *1903a*) shows the northern extremity of this deposit, and illustrates its relation to the glacial valley of the Illinois river. North of Pekin, in Tazewell county, the Illinois river cuts through the Shelbyville and Bloomington moraines, flowing close to high bluffs on its left (eastern) side. From this point southward the river crosses the broad glacial valley diagonally toward the right, exposing a triangular area of lowland between the channel and the east bluffs. The sand is deposited in this glacial flood-plain. At Pekin the plain is about two miles (3 km.) wide; below that city it widens more abruptly, and near Green Valley is 14 miles (22 km.) wide. At some places near the river the plain is covered with modern alluvial deposits, and it is crossed by the Mackinaw river with its broad flood-plain. The remaining area is occupied by sand and by a sandy loam, shown in the Soil Survey as Miami sandy loam. The latter lies at a lower level and represents the original alluvial deposits upon which the sand has been superposed. In this county 22,976 acres (90 sq. km.) are covered with sand. South of Tazewell county the plain retains its maximum width across Mason county, and then becomes gradually narrower toward the south, terminating near Meredosia, Morgan county, with a total length of approximately 75 miles (120 km.). While sand deposits occupy only a portion of this area, their aggregate extent is large and has been estimated (Hart and Gleason, *1907:* 145, 146) at 179,200 acres (700 sq. km.).

The Chicago, Peoria and St. Louis railway traverses the areas from Peoria through Havana to Virginia, and a good idea of the general topography may be gained from its trains. The exposed areas of Miami sandy loam, which forms the foundation of the whole, are irregular in shape and extremely variable in size, ranging from a few acres up to several square miles. They are almost entirely under cultivation. Above them rise the low sand hills (Pl. I, Fig. 1), usually gently undulating at their margins but, if large in extent, frequently quite level toward the center. These vary in size from mere hills of a few acres up to continuous deposits several miles in extent. Their average height is probably 20-30 feet (6-10 m.), but isolated

dunes rise much higher. One of the highest lies about four miles (6 km.) north of Topeka, and is probably about 60 feet (18 m.) above the general level. Part of the sand was originally covered with prairie, but most of this has been destroyed by cultivation and pasturing, so that only a few small areas remain in their natural condition. A larger portion has been forested, and much of it remains in its virgin state. Particularly large tracts of forest are situated near Forest City and between Kilbourne and Bath.

The Hanover Area.—This region of sand deposition takes its name from the station of the Chicago, Burlington and Quincy railway in Jo Daviess county, which lies near the location of the best development of sand vegetation. As in the Havana area the sand occupies the so-called second bottom, between the bluffs on the east and the Mississippi river on the west. In some places the sand extends to the river's edge, in others a strip of alluvial forested flood-plain intervenes. In the northern portion of the county the bluffs lie close to the river and the sand is limited to small isolated areas. In the southern half the bluffs and river become one to three miles (2-5 km.) apart, affording space for an extensive sand deposit. North of Savanna, in Carroll county, the river again flows directly at the base of the bluffs. The area in Jo Daviess county covered by sand is estimated at 5700 acres (22 sq. km.).

Unlike the Havana area, the sand deposits here are nearly continuous and unbroken by intervening areas of a different soil. The surface of the area is gently rolling, with virtually no extensive level tracts. Its general elevation is about 25 feet (8 m.) above the river, but isolated dunes reach a much greater height. Near the eastern margin of the valley the depth of sand abruptly decreases, leaving a trough-like valley extending for a long distance at the base of the bluffs. The Chicago, Burlington and Quincy railway lies mainly in this depression. The drainage from the hills enters the valley through a number of small spring-fed streams. None of these has sufficient energy to erode a valley through the sand, and their discharge merely accumulates in a series of swamps, which are drained by percolation through the sand into the river beyond. The swamps are not continuous, but are separated by tracts of moist ground, originally prairie (the lower prairie of Pepoon, *1909:* 526) but now almost entirely under cultivation.

The sand deposit is chiefly prairie, but a belt of forest lies along the river, and tongues and irregular areas of forest project out into the prairie, in some places extending nearly across. Some of the forest and most of the prairie have been placed under cultivation, but

extensive areas of each are still in their original condition, or but slightly modified by pasturing.

Below Savanna, sand deposits of the same age again appear and continue intermittently down the Mississippi into Rock Island county, where they connect with those of the Oquawka area described later.

The geological origin of these two sand areas is known with considerable accuracy. Both are approximately contemporaneous and are derived from outwash from the Wisconsin glaciers. The method of deposition has been well described by Chamberlin and Salisbury (*1885:* 261, 262), with special reference to the Hanover area.

"*The fringing deposits of glacial waters.*—Outside the moraine lie two classes of deposits which gathered apace with it. The precipitation which fell upon the western slope of the glacial lobe, together with the water which arose from the same part of the glacier by melting, was shed from the edge, except the portion which may have found exit beneath in other directions and the portion lost by evaporation. Copious streams were doubtless the result. It is not difficult to understand that these, as they issued from the glacier, should have been exceptionally charged with silt, sand, and rolling stone, and that, as turbid waters, they poured down the channel-ways that were open to them. Long trains of glacial wash stretching away from the edge of the ice and leading down the several valleys testify to the reality of such streams.

"The most notable flood-train originating on the actual border of the driftless region is that which stretches down the valley of the Wisconsin River. The edge of the ice lobe crossed the Wisconsin in the western part of Dane and Sauk counties. In the immediate valley of the river the moraine is largely composed of gravelly constituents, disposed in kame-like hills and ridges, or undulatory and pitted plains, showing the combined action of wash and push on the part of the glacier and its waters. Originating from this gravelly moraine, there stretches away a flood-train of gravel and sand, reaching down the valley to the Mississippi, and, there joining similar gravel streams originating higher up, it continues down through the driftless area and beyond, though only remnants now remain. This valley drift originates at a height of about 90 feet above the present level of the Wisconsin River, and as it stretches down the valley gradually declines, so that, as it leaves the driftless region, it is barely 50 feet above the Mississippi. Near its origin coarse cobbles, bowlderets, and even occasional bowlders are not infrequent. Farther down, the material becomes finer, and, in the lower stretches, only pebbles and sand are found. The lessening coarseness of the deposit

seems to show that as the glacial waters issued from the edge of the ice they were overloaded and struggling with a burden too great for their complete mastery; and, while they successfully carried the silt, sand, and even some of the finer gravel far down their courses, the heavier material in large part lodged near its origin and progressively filled the bottom of the channel.

"This phenomenon, of which the Wisconsin Valley presents the only complete example lying entirely within the driftless region, finds other examples in several streams which cross the region. The Black River, the Chippewa, the Mississippi, and the Zumbro are all attended by such glacial flood deposits, which may be traced back to their origin on the face of the outer moraine. All these glacial flood plains slope more rapidly than the present streams. The train in the Chippewa Valley falls a little more than six feet per mile in the first 40 miles of its course, and over five feet per mile from its source on the face of the moraine to the Mississippi. In crossing the driftless area the glacial flood plain of the Mississippi declines about 50 feet more than the present stream."

Their description applies as well to the sands of the Havana area, except that the source of the latter is the outwash through the Bloomington moraine in the vicinity, as already described by Hart (Hart and Gleason, *1907:* 139-144).

The Amboy Area.—This name is given in this report to the irregular complex of sand ridges and marshes along the Green river in Lee county, well illustrated in the vicinity of Amboy. Near that place the sand occupies a strip about four miles (6 km.) wide on the south (left) bank of the river. It lies usually in comparatively narrow ridges from 20-50 feet (6-15 m.) above the intervening marshes. Back from the river the ridges are broader and the marshes proportionately more limited in size. Numerous small undrained ponds and swamps lie among the ridges. Near Amboy the ridges are either forested or under cultivation, but the number of prairie species occupying the roadsides indicates that at least a portion of the sand was originally covered with prairie.

Alternating areas of swamp and sand border Green river along its whole course through Lee, Bureau, and Henry counties to its junction with Rock river, a distance of about 70 miles (110 km.). They are to be regarded as outwash from the Bloomington morainal system, which crosses the south part of Lee county from northeast to southwest (Leverett, *1899:* 277, 492, 493). The drainage of the whole valley is poor, and two large marsh areas, known as the Inlet Swamp and the Winnebago Swamp, are as yet not entirely reclaimed.

Probably the present local swamps are the vestiges of large continuous marshes which formerly extended the whole length of the river, and the hydrophytic plant associations now between the dunes are doubtless the survivors of an earlier swamp vegetation. Slow drainage has permitted the formation of extensive muck deposits, while in the Illinois river valley more rapid and complete drainage has merely left areas of a sandy loam between the dunes.

The Dixon Area.—A small outlier of this general area, situated four miles (6 km.) southwest of the city of Dixon, is referred to under this name in the subsequent pages. This area is not forested, but the small marshes among the dunes indicate by their vegetation a close similarity to the rest of the area.

The Oquawka Area.—Below the mouth of Rock river the Mississippi turns sharply to the south and follows a generally southerly direction for about 60 miles (100 km.). Through this portion of its course, from Muscatine, Iowa, to Ft. Madison, Iowa, its valley is well filled with sand deposits. These are probably chiefly a continuation of those along Green river, derived from outwash from the Bloomington moraine. It is possible that some of the sand is derived from the Wisconsin river outwash, as described above under the Hanover area.

At the northern end of this area the principal deposits lie on the Iowa side of the river, where their vegetation has been briefly described by Pammel (*1899*). In Illinois the sand extends in a strip through the western part of Mercer and Henderson counties, lying usually close to the river, and gradually becoming thinner and less nearly continuous toward the south. A branch of the Chicago, Burlington and Quincy railway crosses the deposits between Aledo and New Boston and follows them south from Arpee to the junction with the main line at Gladstone. The town of Oquawka is situated on the deposits, and is a convenient location for the study of the sand vegetation.

At the north end of Henderson county the sand lies in large, continuous, nearly level areas, with here and there at wide intervals a low ridge. Its general height is 30-50 feet (10-15 m.) above the river. The ridges rise a few feet higher and near the Mississippi the river dune reaches a maximum height of about 100 feet (30 m.). Toward the south the sand lies in irregular, gently rolling ridges, not more than 30 feet (9 m.) high, and separated by areas of a sandy loam. South of Oquawka the deposits are broken by the Henderson river, but beyond it low ridges reappear and continue to the southern edge of the county.

A large proportion of the area has been forested, and most of that part is not under cultivation. Some fields have been cleared and abandoned, and are now densely covered with a thick growth of small trees. The portion originally covered with prairie is almost entirely under cultivation. Some large areas of blowsand occur, caused in many cases by pasturing or plowing. A conspicuous instance may be seen just south of Keithsburg, where the railroad passes through a blowout complex, with one large traveling dune.

The Kankakee Area.—This is undoubtedly the largest sand area represented in the state, but at least three fourths of its total extent lies in Indiana. Leverett (*1899:* 328-338) has given a detailed account of its extent and thickness, and from him the following statements are taken. The sand occupies a roughly semicircular area, with the curved edge to the south. Beginning in western Marshall county, Indiana, the sand margin curves to the south and southwest near the Tippecanoe river, passes westward near the towns of Monticello and Kentland into Iroquois county, Illinois, and thence follows the Iroquois river north to the Kankakee river, which forms the northern boundary of the area. This area includes about 3000 square miles (7500 sq. km.). The deepest deposits lie near the Kankakee river, where the sand extends "several feet below the level of the base of the ridges."

As in other areas the sand is not necessarily continuous. Especially near the border of the area it is heaped into irregular ridges and dunes, probably caused by wind, and between them lie areas of sandy loam or muck. As in the Amboy area, the appearance indicates a slow recession of water, with the last of the hydrophytic vegetation still persisting. While the presence of the sand is certainly due to glacial outwash, Leverett does not give more definite conclusions.

At the present time all the upland sand ridges are either forested or under cultivation, while the lowlands of peat, muck, or loam are occupied by swamp or meadow associations. Brief notes on the vegetation, with maps showing the distribution of the sand in Newton and Marshall counties, Indiana, have been published by the Bureau of Soils (Neill and Tharp, *1907*; Bennett and Ely, *1905*). But little attention has been given to this area during the present investigation.

The Winnebago Area.—This series of sand deposits lies chiefly in the northern part of Winnebago county, Illinois, and the southern part of Rock county, Wisconsin. It has been mapped and described by the Soil Survey (Bonsteel, *1903b*; Coffey, Ely, and Mann, *1904*). The sand lies between the valleys of Sugar river and Rock river, in

level areas or low ridges with a generally east and west direction, and has a total extent, as estimated by the Bureau of Soils, of 25,088 acres (100 sq. km.).

This sand differs essentially from the other areas described in its upland position. In some places it forms the bluffs of Sugar river, but in the center of its area it occupies the highest ground between the two river valleys and over 100 feet (30 m.) above them. Its position indicates that it is not of fluviatile or lacustrine origin, as stated in the Soil Survey report. Leverett's account of its origin (*1899:* 131-138) is the most satisfactory, connecting the sand with the invasion of the Iowan glaciers. The western border of the Iowan glaciation enters Illinois at the valley of Sugar river, extends south along that river and southwestward along Pecatonica river to the western edge of the county, and thence east to the Rock river. The particular area of sand deposition is thus within the limits of the Iowan glaciers, and the sand itself is regarded by Leverett as the drift of the Iowan invasion.

There is no present evidence of the recent existence of extensive prairies in the Winnebago area. Aside from a few deep depressions with a hydrophytic vegetation, the whole area is either forested or under cultivation.

Climate

The general climatic conditions of the northern and central parts of Illinois are shown in the following diagrams, taken from Henry (*1906*). Dubuque, Iowa, is located on the Mississippi river just north of the Hanover sand area. Beloit, Wisconsin, is situated on the Wisconsin-Illinois state line at the eastern edge of the Winnebago area. Keokuk, Iowa, is on the Mississippi river, near the southern end of the Oquawka area. Springfield, Illinois, is in the central part of the state, east and southeast of the Havana area. Peoria, Illinois, is on the Illinois river, at the northern end of the Havana area. The first four stations, being located at the extreme edges of the general sand areas of the state, will indicate the extremes of climate at the north and south, and the conditions of the intervening region may be approximated by interpolation. Figure 1 shows that the seasonal distribution of heat is of the continental type, with moderately cold winters and hot summers, and with occasional great extremes of heat and cold. It may again be mentioned that the official temperatures, taken under a shelter of regular pattern, do not represent the actual temperature to which plants are exposed. This is particularly true of plants growing in exposed sand, where the surface temperature in

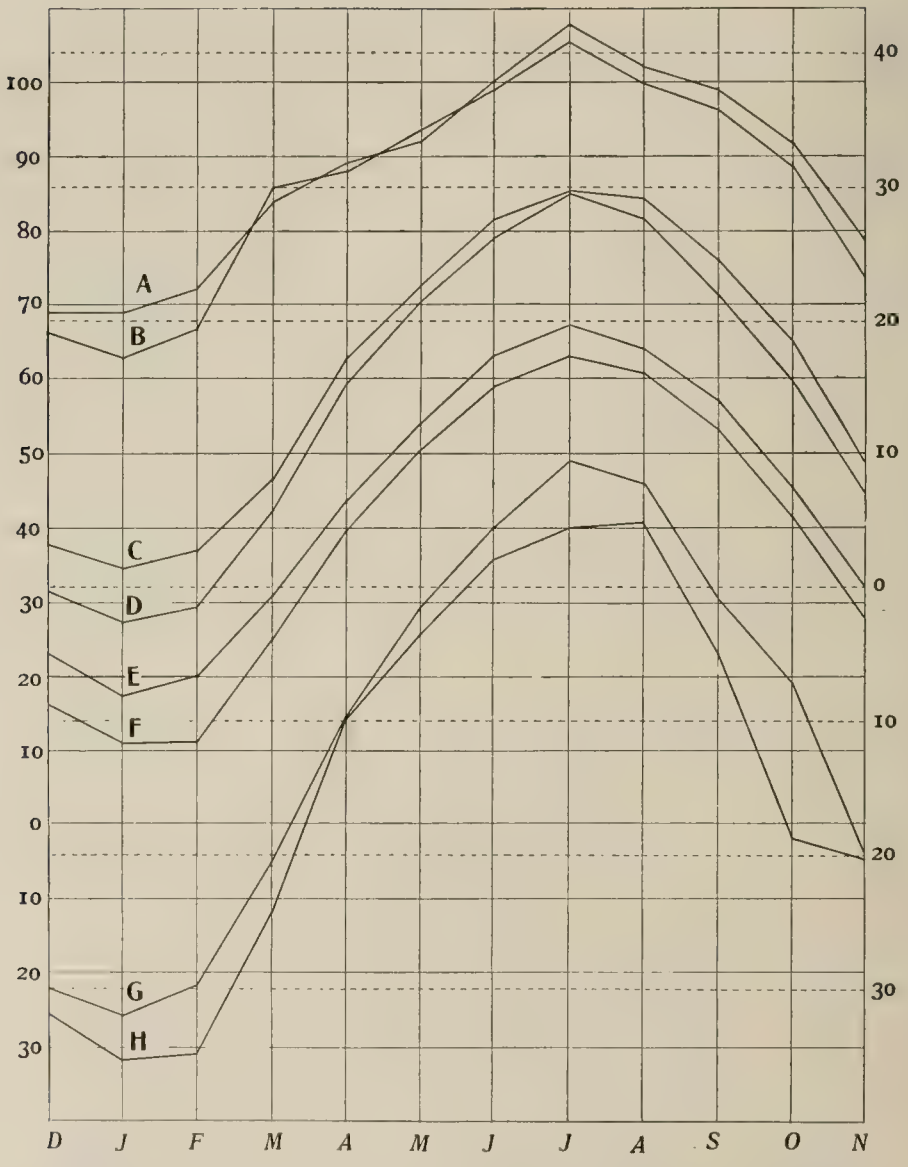

Fig. 1. Temperature curves for Dubuque, Beloit, Keokuk, and Springfield, from December to November, expressed in degrees Fahrenheit (left) and Centigrade (right): *A*, absolute maximum for Keokuk and Springfield, *B*, for Dubuque and Beloit; *C*, mean maximum for Keokuk and Springfield, *D*, for Dubuque and Beloit; *E*, mean minimum for Keokuk and Springfield, *F*, for Dubuque and Beloit; *G*, absolute minimum for Keokuk and Springfield, *H*, for Dubuque and Beloit.

summer may exceed 130° F. (55° C.). According to Mosier (*1903*) the average date of the last frost in spring is April 29 in northern Illinois and April 21 in the central portion, while the first frosts in autumn occur on October 6 and 10, respectively. The average length of the growing season is accordingly from 160 to 172 days, depending on the latitude.

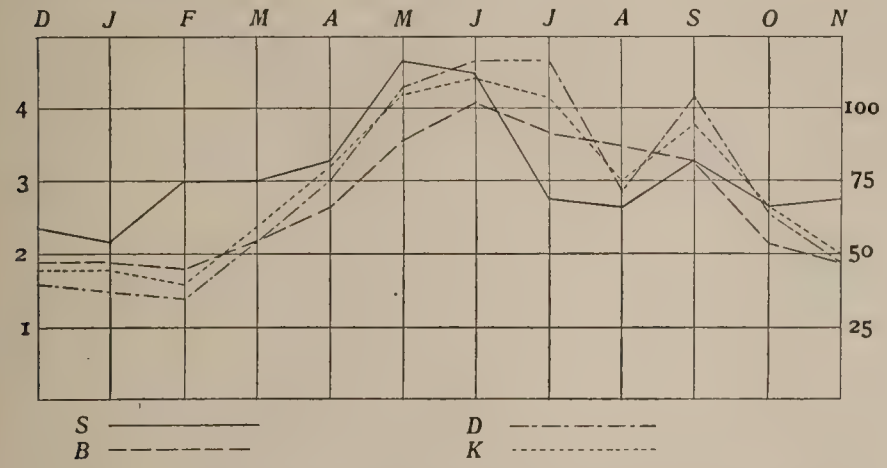

Fig. 2. Rainfall curves for Dubuque, Beloit, Keokuk, and Springfield, from December to November, expressed in inches (left) and millimeters (right).

The rainfall, as shown in Figure 2, is unequally distributed, the greater portion falling during the growing season. The resulting dry winters are probably somewhat favorable to the perpetuation of the prairie formations (Schimper, *1903*). The number of days with 0.01 inch of rainfall or more varies from 75 per year at Beloit to 117 at Dubuque, and of these from 35 to 52 occur during the growing season.

Comparing the preceding statements with the curve of total sunshine (Figure 3), it becomes evident that the comparatively rainy summer months have the greatest proportion of sunshine. This implies heavy rains separated by days of hot dry weather, and leading to a generally xerophytic season in late summer. This climatic feature has already been commented upon (Schimper, *1903*) as in a measure conducive to a prairie type of vegetation.

Further climatological data might be included, but it is believed that these will give a sufficiently complete idea of the general climate of the region. The details of plant distribution are in nowise affected by the broad features of climate.

Fig. 3. Sunshine curves for Dubuque and Peoria, from December to November, expressed in per cent. of total possible sunshine.

The Ecological Environment

In each area the sand has essentially the same structure. It is fine grained, yellowish brown in color, and virtually free from organic matter except in the upper layers. In those portions occupied by prairie, and in a part of the forests, the surface is exposed and considerable loose sand is shifted by every wind.

The ecological nature of sand as an environment for plants has been so frequently described that further discussion here is unnecessary, especially since it is probable that no important additions can be made to our knowledge of the subject without careful field experimentation. Some of the best treatments of the matter in English may be found in the works by Cowles (*1899*), Warming (*1909*), Olsson-Seffer (*1909*), and Schimper (*1903*), and in them fuller reference is made to the literature. Briefly summarized, it may be stated that in sand deposits (1) the temperature shows a great variation from day to night and from surface to subsoil; (2) in open associations the insolation is increased by reflection; (3) the water capacity is low and the available supply is small in amount, but constant, because of atmospheric condensations; (4) the amount of soluble inorganic salts and of organic matter is small; (5) in open associations the surface sand is constantly shifting, resulting always in an unstable environment and sometimes in large excavations or accumulations.

Of these conditions, the last exerts the most apparent and the most important influence on the associational distribution of the vegetation.

The other four are probably responsible chiefly for the *selection* of a sand flora from those species which are located within invading distance of the area in question. They certainly can not account for the sharp differentiation of the vegetation into definite associations. In this the plants themselves are most concerned, through their modification and control of the physical features of the environment. If their control is lost, a successional series begins. In the field study, it was usually possible to recognize in the dynamic trend of the vegetation the underlying cause. The descriptions which follow take up the subject from this aspect, discussing in more detail the effect of the dynamic environment, especially the wind, and its partial or complete control by the vegetation.

General Discussion

In the field study upon which this work is based the observational method has been used almost exclusively. No apology or justification for this method is necessary, for direct observation has led in the past and will lead in the future to some of the most important results of plant ecology, and must always be the method by which the first ecological work in any region is done. The value of an exact knowledge of some of the physical features of the environment is evident, but their evaluation in an area of considerable size is a task not to be undertaken by one man or completed in a single season. Undue emphasis on the environment may lead to the partial neglect of the most important feature of a region, the vegetation. The plant itself is in many cases the controlling agent in the environment; the differentiation of definite associations is mainly due to the interrelation of the component plants; and the physical environment is as often the result as the cause of the vegetation. The relative importance of the plant covering and the physical environment is happily expressed by Spalding (*1909:* 477, 479): "But little reflection is needed to arrive at the conclusion that the classical question regarding the relative importance of physical constitution and chemical composition of the substratum to plant growth * * * does not, and can not reach the heart of the problem. * * * This being the case, it would seem that in the future, investigations of the habitat relations, of the desert species especially, must be directed mainly to the plant itself. * * * The establishment of a plant in the place which it occupies is conditioned quite as much by the influence of other plants as by that of the physical environment."

In the prairies of the sand deposits the two chief dynamic features

of the environment are wind, which tends to move the sand, and vegetation, which tends to stabilize it. These two opposing forces are primarily responsible for the present location of every association. In the forested portion of the sand the water factor is apparently the most important, but it depends chiefly upon the influence of the vegetation rather than upon any truly physical condition. In a broader way, the presence of a particular flora in the sand is due partly to the selection from the surrounding associations of various species with certain physiological requirements, and partly to climatic changes in the past. The latter can only be conjectured; the former are not known for any plants in this state and for very few in any place. According to these views, physical factors are relatively little concerned in the development of vegetational structures in this region, while the demands of the plant and the effects of its growth are of chief importance.

The delimitation of the various associations concerned is also a matter which must depend, for the present at least, upon direct observation. Jaccard (*1902*) has given a method for comparing different associations and stating numerically the degree of difference between them. This has been used frequently and has given some comparisons which are interesting rather than important. It can not, however, be used successfully in the field. The chief difficulty in separating associations lies in the idea of the association itself, which has never been expressed with sufficient clearness.* By some this idea has never been received with favor. It is true that the distinctness of the associations is lost and their character greatly modified by the effects of civilization, but experience in natural conditions justifies the statement that associations are definite organized units and that all vegetation is composed of them, either mature and fully differentiated or in process of organization (cf. Harper, *1906:* 33, 34). It is as difficult to formulate a satisfactory definition of an association as of a species, and as unnecessary. For the present it may be considered that it is a homogeneous area of vegetation in which the interrelations of the component individual plants permit them to endure the physical environment.

In this work the recognition of associations has been based upon the idea of uniformity, and those areas, whether large or small,

*The concepts of the association as expressed by authors are very variable and frequently conflicting. Some demand that each association shall occupy a definite habitat (Clements, *1905:* 292), others allow a wide range in environment (Cowles, *1901:* 79); some consider that the change of a single species affects the nature of the association (Harshberger, *1900:* 652), while others permit a large variation in the flora (Warming, *1909:* 145, 146).

which are homogeneous (Clements, *1904:* 11) throughout their extent have been considered members of the same association. This uniformity is shown by the environment, by the behavior of the vegetation, and, above all, by the plants themselves.

In a region of limited size, over which the climate is essentially the same, the physical environment of an association is usually nearly constant, although instances are not lacking of an association living in the same area under widely different conditions (Cowles, *1901:* 79). On the other hand, it is not necessary that every area with the same environment should be occupied by one association. It is regularly the case in the sand region, and usually also elsewhere, that if the areas of the associations are conditioned by the environment, a considerable and observable change is necessary to influence the vegetation (Clements, *1905:* 292). But in no case should the recognition and delimitation of associations be based upon the environment alone, which leads to a classification of habitat rather than vegetation (Gradmann, *1909*) and may lead to the uniting of radically different types of vegetation.* The behavior of the vegetation with respect to adjacent areas is shown by successions which take place between them. If two areas with essentially the same environment show no successional relations it is probable that they represent different consocies of the same association.

But the first test of a plant association must be the vegetation itself. No two areas of vegetation are exactly similar, either in species, the relative number of individuals of each, or their spatial arrangement, and the smaller the areas to be compared the greater proportionately are the differences between them. Also, with continued and more detailed observation the importance of these minor variations is magnified, and tends to lead to the recognition of an unwieldy number of minor groups unworthy of the rank of association. This introduces the question of how great a variation may occur in the structure of the vegetation without the identity of the association being changed. Field work shows that the dominant and the secondary species may both vary independently. In the same association the dominant species, if more than one, will have the same vegetative form, as bunch-grasses, or trees, and will be of nearly the same size. Excessive development of one of them to the partial or complete exclusion of the others makes no change in the general ap-

*The classification of associations by Clements (*1905:* 302, 303) is largely of this nature, and in some cases leads to the wide separation of closely related associations or even to the placing of a particular area in two different groups. Thus a hydrophytic sand-bar (*cheradium*) may be converted into a new xerophytic "formation" (*syrtidium*) merely by the fall of the water in the river.

pearance of the vegetation and does not affect the growth of the secondary forms. There are frequently no successional relations between these local areas, or consocies. Areas characterized by dominant species of widely different appearance can not be regarded as belonging to the same association unless it can be shown that the areas represent transitory stages of development, as described below for the stabilization of blowouts. If the dominant species have the same general form, but do not tend to mix, except in the tension zone between them, and are accompanied by different groups of secondary species, the occurrence of different associations is suggested, as in the black oak and bur oak forests.

The secondary species occupy a comparatively small area in the associations and their number usually depends in some way upon the habits of the dominant species. This is well illustrated by the bunch-grass association, in which the secondary species are absolutely dependent upon the dominant bunch-grasses. More species are concerned and their distribution is frequently irregular. These irregularities, however, are seldom coincident with any variation in the dominant plants, but are caused chiefly by competition for space regulated by seed dispersal and seasonal climatic fluctuations. A considerable variation in their quantitative distribution may be expected, unless they belong to the derived element of the association (see below), in which case they may indicate the beginning or the end of a succession or some local change in the environment which is nevertheless not sufficient to induce a change in the dominant species.

Two areas of vegetation dominated by different species are accordingly probably consocies of the same association if (1) there is no obvious difference in their environments; (2) if there is no evidence of succession between them; (3) if the secondary species are the same for each; (4) if the dominant species are of the same vegetative form or (5) tend to mingle in other areas with the same environment and secondary species.

A slight deviation from these criteria may be neglected if there is a preponderance of agreement with them, while a radical deviation would indicate that the areas represent distinct associations. In most cases (in the sand areas, at least) their application in the study of the vegetation leads to definite and unquestionable results.

Whether small or large, associations usually contain some species which are more characteristic of other areas. This *derived element* can be recognized only by comparison with neighboring associations, where the species in question are more numerous, more general in distribution, or more luxuriant in growth. They are least abundant

near the center of the association, and tend to increase progressively toward its boundaries. The best idea of the structure of an association is accordingly gained at its center. The presence of a derived element is well illustrated in the black oak association, in which every spot of unshaded exposed sand is occupied by interstitial annuals of the bunch-grass association, while near the margin of the forest numerous prairie perennials and grasses also occur. Many species, naturally, are almost equally typical of two or more associations.

The boundary of an association is frequently sharp and well defined, especially if the dominant species of the adjoining areas are of different vegetation forms, as between prairie and forest, or if the associations are correlated with considerable and relatively constant differences in the environment, as between the windward slope and basin in the blowout formation. In other cases the boundary is broad and more or less indefinite. This is particularly true if the dominant species are of the same vegetation form or if the environmental difference is fluctuating, as, for example, between the bunch-grass and the *Panicum pseudopubescens* associations. The vegetation of these transition zones is a mixture of usually indefinite and frequently highly variable character. The species in them should be referred as far as possible to their respective associations, and not allowed to modify the ideas of structure gained from an examination of more typical localities.

Besides these transitions in space, there are also transitions in time. An early stage in the development of an association may resemble but little its mature condition. Certain members of the association with excessive seed production, with more mobile seeds, or better adapted to the somewhat aberrant environment, appear first and for a time dominate the area. Thus, in the stabilization of a blowout, the redevelopment of the bunch-grass association begins with a growth of *Lespedeza capitata* and *Oenothera rhombipetala* in large quantities. This condition lasts but a short time before they are replaced by the usual bunch-grasses. Such an area is at first suggestive of a distinct association, but examination shows that it has no species, aside from relics of the preceding vegetation, not found also in the bunch-grass, and that the environmental conditions are very similar to those of the spaces between the bunches of grass, where these interstitials (p. 54) grow. A knowledge of the habitat preferences and habits of the component species and of the general dynamics of the area is necessary to decide upon the proper classification of these transitional stages.

In estimating the uniformity of the vegetation, direct observation

is in many cases satisfactory, especially if the associations are small in area or the component plants low in stature so that a comprehensive view of them may be taken. In other cases, simple lists of species, taken in each area of the association, may be compared, and their similarity is a good index. For more accurate work, the quadrat method proposed by Clements (*1905:* 161-170) may be employed. It gives excellent results but demands much time and labor. In areas of closed vegetation it seems to have its chief value in expressing, rather than determining, the structure of the association. A modification of the quadrat method has been tried with success in this work. It consists in listing, in the approximate order of the space occupied by each (not the number of individuals), the species on an imaginary quadrat of about four square meters situated directly in front of the observer. Stepping forward two paces brings another quadrat to view, and a series of ten or twenty, extending in a continuous strip or scattered throughout the association, may be listed in a short time. The size of the quadrat used is chosen to suit the character of the vegetation; two meters square seems adequate in the study of prairie associations. In a forest a quadrat of that size could be used only for the herbaceous vegetation, and one ten meters square would be necessary to show the nature of the forest cover. Quadrats of such size are unwieldy, and in practice it has been found that results are more easily obtained by counting every tree within five meters of the observer as he walks through the forest. A new list may be made for each hundred meters or for any area with distinct environment.

In investigating the tension zone between associations the transect method (Clements, *1905:* 176-179) may be used, but is subject to the same limitation as the quadrat method. Good results may be conveniently obtained by walking back and forth repeatedly from one association to the other, listing the species in the order of their appearance.

Carefully conducted studies, as indicated above, show that the dominant species are uniformly distributed over the whole area of the association or consocies, and that the floral discrepancies are caused by a number of comparatively rare species represented usually by a small number of individuals. The weakness of the whole method lies in the fact that, in a mere list, a rare species, possibly a single individual, is given as much weight as a common one. Actual counts of the individuals of each are difficult to make and may give misleading results. If each species could be correlated with the proportion of the area which it occupies, it would be demonstrated that most parts of an association are highly similar in structure, and the

resulting community coefficient of different areas would probably be above 0.900 (in the black oak association virtually 1.000). Unfortunately no practical method for this has been devised.

The more widely the different areas of an association are separated, the greater are the floral discrepancies. The dominant species, however, remain constant, and the change lies almost wholly in the secondary species. Many of these are the results of selective migration from neighboring associations, so that a variation in the general nature of the vegetation of an area affects the specific structure of each association. This phenomenon has been discussed briefly by Warming (*1909:* 145, 146) under the name of geographical variation. It is well illustrated in the sand areas of Illinois by the secondary species in the black oak association. In the Havana area are found some typically southern species, as *Quercus marilandica* and *Galium pilosum,* while in the Winnebago area some species of northern or eastern distribution occur, as *Pyrus americana* and *Lupinus perennis.* In comparing areas of such wide geographic separation emphasis must be placed upon the dominant species, which are the fundamental cause of the general physiognomy of the association.

The areal distribution of an association may be compared to the distribution of a species. Both are irregular in outline, although coextensive with certain combinations of environmental factors. Both consist of scattered members, independent of each other, but related by a common genesis and common demands upon the environment. Both show minor local and broad geographical varieties. The former are illustrated in the association by the consocies; the latter, in the species by the subspecies, which in their typical form occupy outlying arms or peninsulas but toward the center of distribution intergrade with the main body of the species. Taxonomic work has shown that the interpretation and classification of these forms is a matter of great difficulty. Proper treatment of the geographical varieties of an association will be a matter of much greater difficulty, since the necessary comparisons must be based entirely upon written description or photographic record.

Because of this geographical variation and consequent difficulty of comparison, few correlations of associations in different parts of America have been made or attempted. Ecological literature contains numerous descriptions taken from the few representatives of the associations in a limited locality, but as yet no one has given a general description of an association, compiled from observations taken

throughout its range.* In this respect the present status of systematic ecology resembles that of pre-Linnaean taxonomy, a maze of detached facts waiting for a Linnaeus to collate and correlate them into a foundation for future investigation.

The associations recognized in the field have been grouped into formations, characterized partly by uniformity in the physiognomy of the vegetation, and partly by uniformity of environment, to which the physiognomy is in some extent due. Formations correspond somewhat to genera in taxonomy, and like them may be limited or comprehensive in their scope, this depending solely upon individual opinion. As far as possible they have been made to coincide with the popular idea of the different types of vegetation. The four formations are all generally known through the sand regions and given the names used here, with the exception of the forest, which is colloquially known as "timber" or, in some places, as "black-jack." The latter term applies to the particular association rather than to the forest formation in general. The areal extent of a formation is approximately coincident with one of the phytogeographical provinces of North America, and formations with the same distribution are placed in the same province. It is thus seen that the differentiation of both minor and major ecological groups depends principally upon the plants themselves, the associations being distinguished by the specific composition, the formations by the general appearance, and the province by the distribution of the vegetation. This is an extension of the idea already expressed, that the most important feature of the association is not the habitat but the plant. It is believed that the regional classification of associations is really genetic and dynamic, bringing together those which are most closely related by origin and succession.

The Vegetation

The area covered by the state of Illinois occupies a unique position in respect to the vegetation of the continent, marking the region of closest approximation of four great floral and vegetational provinces. (See maps in Schimper, *1903*; Engler, *1902*; Transeau, *1903*, *1905*; Merriam, *1898*; Sargent, *1884*.)

The Austroriparian Province (Merriam, *1898:* 45) enters the state at the extreme southern end, and well-developed examples of its dominant hydrophytic vegetation, the cypress swamp (*Taxodium distichum*), extend northward into the lower valley of the Wabash

*The nearest approach to this has been made by Transeau (*1903: 1905-6*) in his studies of bog floras.

river. Scattered species of Austroriparian affinity extend north in ever decreasing numbers, for some 300 miles (500 km.). One of the most conspicuous plants of this nature is *Carya illinoensis,* the pecan, which follows the alluvial bottom-land of the Mississippi river as far as southeastern Minnesota. Few species of this group occur on the sand deposits of northern and central Illinois, although a number occupy the sand-bars of the lower Mississippi.

The southern boundary of the great Northeastern Conifer Province of the north and northeast passes southeastward across Wisconsin and Michigan, and numerous species persist south of this line. Definite but isolated associations of *Pinus Strobus* and of *Larix laricina,* each with its usual attendant species, are found in various places in northern Illinois, and many scattered species of northern range, such as *Populus tremuloides* and *Betula alba,* var. *papyrifera,* live in associations of other provinces. Some of them are concerned in the vegetation of the sand deposits.

Between the Austroriparian Province on the south and the Northeastern Conifer Province on the north there are extensive plains, reaching from the base of the Appalachian mountain system on the east to Nebraska on the west. This area is known as the Deciduous Forest Province, and is occupied, as its name indicates, by deciduous forests, with *Quercus, Acer, Fraxinus, Tilia, Fagus, Nyssa, Liriodendron, Aesculus,* and *Carya* as some of the leading genera. In the eastern part of the province the forest is almost continuous, broken only by minor associations of an edaphic nature. At the west, from Indiana and Illinois to Nebraska, it becomes discontinuous, and a portion of the area, becoming proportionately larger westward, is occupied by the prairies.

The Prairie Province, last on the list, extends in a long strip north and south through the Great Plains at the eastern base of the Rocky Mountains from Texas to Saskatchewan, and an eastward extension passes across Iowa and Illinois into Indiana, sharing the area with the deciduous forests (Pound and Clements, *1898*). Throughout its whole area the dominant vegetation is prairie.

Each of these four provinces is composed of many plant associations, which occupy usually definite habitats, and which are related to each other by certain successional trends. In each there are associations occupying limited areas of extreme environment, and these tend to converge, through the effect of various physiographic and biotic agencies, toward the dominant or climax vegetation of the region. In each of the provinces the successional events in the establishment of the dominant vegetation are relatively simple. There

is in every case at least a hydrophytic and a xerophytic extreme, forming two general converging lines of succession. In our present knowledge of the subject, it is impossible to state whether there is one definite climax association in each province; it seems probable that there are several such associations, each characteristic of a limited portion. It is certain that in each province there is a dominant *formation,* or type of vegetation, deciduous forest, coniferous forest, or prairie, as the case may be. Present evidence seems to indicate that the nature of the dominant type is determined by a long chain of historical factors (Adams, *1902*, *1905*) and its present areal distribution by the broader existing climatic factors, notably heat and rainfall (Transeau, *1905*).

The boundaries of the four provinces have been subject to great changes in the past, both during and following the glacial period, as the ice swept to the south, overthrowing the previous conditions of climate, and then retreated to the north, uncovering unoccupied ground and throwing it open to plant invasion. The ensuing movements of vegetation were among the greatest in the history of the continent, and have been of the greatest moment in determining the present distribution of the biota.

These movements have by no means ceased. They are merely less obvious when measured in terms of years and centuries rather than in geological periods. Even now a biotic migration is in progress, which is probably the direct continuation of early postglacial movements, and is doubtless as rapid and as far-reaching in its effects as any of the past.

In the present migration the vegetation of the Deciduous Forest Province is the chief factor. It is now pushing out its boundaries to the north and west and enlarging its area at the expense of the Northeastern Conifer Province on one side and the Prairie Province on the other. Some detailed features of the northern extension have been given by Whitford (*1901*), Transeau (*1905-06*), and others, and summarized by Adams (*1905*). The westward migration has been mentioned by many, but scarcely described in detail.

The actual steps in the migration of the vegetation are due to a series of successions, by which associations of the prairie or of the coniferous forest are replaced by others, with similar environmental demands, from the deciduous forest. Some of the northern and western associations are succeeded with comparative ease; others resist succession for long periods of time. Because of this the forest extends north and west, not in continuous masses but in long tongues and detached bodies, while relics of the former vegetation lag be-

hind as isolated areas in the midst of the forest. Relics of the northern coniferous forest persist in Illinois as tamarack swamps and groves of white pine, and both are frequently termed "boreal islands." In a similar way the detached areas of prairie in Illinois may be regarded as western relics, although they are often miles in extent. The oldest relics, that is, those toward the east or south, are regularly smaller in extent and more mixed with forest species (Bonser, *1903*). In the migration of the deciduous forest associations, the greatest advance has always been made in those habitats which most nearly resemble those occupied by the climax formation, and which are therefore most nearly suited to the invading vegetation. On the other hand the relic associations have been left behind in those habitats, not necessarily best adapted to the relic vegetation, which are least suited to the invaders. For this reason the boreal associations in Illinois are limited to sandstone hills and to undrained swamps, while the prairies persist chiefly in the upland soils between the stream courses.

The successions by which the general migration is consummated are of a type different from that found within the formation and leading merely to the dominance of the climax vegetation, since they involve associations of two and sometimes of three provinces. While several descriptions of this type have been published, general conclusions have not usually been drawn. At the present time it can only be stated that the succession seems to take place between equivalent members of the different provincial successional series. Thus, as shown in the following pages, the xerophytic extreme of the prairie, the bunch-grass association, tends to give way to the corresponding extreme of the forest, the black oak association. In a similar way the black oak association may succeed the xerophytic extreme of the Northeastern Conifer Province, the jack-pine association. We find similar relations between the hydrophytic extremes, and in Illinois the succession of the northeastern tamarack association by the deciduous bottom-land forest may be observed.

Northern Illinois, therefore, has been and is the scene of important events in the biogeographical history of the continent. The following description of vegetation is designed to be not merely a discussion of static conditions, but rather a portrayal of one phase of this great vegetational movement and of the consequent struggle for supremacy which is still being waged.

In the vegetation four distinct formations, or types of vegetation, have been recognized. Each of these consists of several associations, characterized by a distinct group of plants, by a distinct habitat, or by

both. The subjoined tabular view will express the classification used, while the arrangement of the associations in the descriptive matter follows as nearly as possible their successional relations.

Classification of the Plant Associations

A. The vegetation is dominated by grasses, occupying a relatively stable habitat with low water-content. The secondary species occupy the interstices between the stools of grass. The Prairie Formation of the Prairie Province.

a. The movement of sand is slow; several species of bunch-grass are present and many secondary perennial species. The Bunch-grass Association.

b. Sand movement is more rapid; the area is dominated by *Panicum pseudopubescens* and the secondary species are chiefly annuals. The *Panicum pseudopubescens* Association.

B. The vegetation is very sparse and open, occupying usually a very unstable habitat due to rapidly shifting sand; there is little distinction between dominant and secondary species. The Blowout Formation of the Prairie Province.

a. The sand movement is chiefly due to removal by gravity; the vegetation consists of relic grasses and perennials. The Windward Slope Association.

b. The sand movement is due chiefly to removal by wind; the extremely sparse vegetation consists of deep-rooted perennials. The Basin Association.

c. The sand movement consists chiefly of a mere redistribution or of gradual deposition; the vegetation is composed chiefly of annuals. The Blowsand Association.

d. The sand movement consists chiefly of a mere redistribution; the vegetation is dominated by the sand-binding perennial, *Hudsonia tomentosa*. The *Hudsonia* Association.

e. The sand movement consists chiefly of deposition; the vegetation is composed of sand-binding perennials with accessory annuals. The Deposit Association.

f. The vegetation occupies a fossil soil, uncovered by continued sand movement; the dominant species is *Stenophyllus capillaris*. The *Stenophyllus* Association.

C. The vegetation is dense, closed or nearly so, with grasses only as secondary species; the sand is stable, with usually relatively high water-content; the formation is developed in deep depressions. The Swamp Formation of the Deciduous Forest Province.

a. The vegetation is semixerophytic, characterized by slender perennials. The *Solidago* Association.

b. The vegetation is truly mesophytic.

1. The vegetation is dominated by willows. The *Salix* Association.
2. The vegetation is dominated by mat-forming mosses. The *Polytrichum* Association.

c. The vegetation is hydrophytic.....The Swamp Association.

D. The vegetation is dense and closed, dominated by trees or avevectent shrubs, or by herbs in the immediate vicinity of shrubs; the sand is stable, with usually low water-content.
The Forest Formation of the Deciduous Forest Province.

a. The vegetation is dominated by herbs.
The *Smilacina* Association.
The *Physalis* Association

b. The vegetation is dominated by shrubs, with numerous lianes, the secondary species are of a mesophytic type.
1. On the crests of dunes or other areas of deposition.
The Dune Thicket Association.
2. In blowouts.....The Blowout Thicket Association.

c. The vegetation is dominated by trees.
1. The secondary species are generally xerophytic; avevectent shrubs or lianes are few or absent; the leaf-mold is thin or absent.
The Black Oak Association.
2. The secondary species are generally mesophytic; avevectent shrubs and lianes are abundant; a superficial layer of humus is developed.
a. The dominant species are bur oak and white oak.
The Bur Oak Association.
b. The dominant vegetation is composed largely of black oak, but with numerous other arborescent species.
The Mixed Forest Association.

The Prairie Formation

The Bunch-grass Association

The bunch-grass association formerly occupied probably more than nine tenths of the unforested portion of the sand areas. It extended over hill and dale, interrupted only by the blowouts and their related associations, and was by far the most important association of the unforested area. Monotonously uniform floristically, its ecological structure showed an obvious differentiation into several consocies, each characterized by the preponderance of one or a few species of grass, and often sharply distinct from its surroundings. These are considered to be consocies instead of associations because they can not be referred to any apparent difference in the environment, and because they exhibit no successional relations to each other.

The best development of the bunch-grass association was, and is, in the Hanover sand area. By far the larger portion of the area was originally unforested. Large fields are still in a virgin condition, and hundreds of acres have been but little pastured. The area includes most of the consocies described and offers without doubt the best conditions for ecological study. The Winnebago area includes, so far as observed, but one small area of bunch-grass, not more than an acre in extent, entirely surrounded by forest. It is evidently a

relic of a former wider extension of the association. In the Amboy area most of the country is either forested or pastured, and the only observed examples of bunch-grass were scattered fragments along the roadsides. The Dixon area formerly contained much bunch-grass, but it is also now largely under cultivation. The Oquawka area is more extensively forested, but some of the bunch-grass still remains in the original condition. The *Leptoloma cognatum* consocies is especially well represented there. The bunch-grass association formerly occupied thousands of acres in the Havana area, but most of it is now under cultivation.

In the three chief sand areas, at Hanover, Oquawka, and Havana, the sand deposits lie, as has already been noted, on the east side of a river, extending from the water's edge to the bluff. The bunch-grass association is always separated from the river by a narrow or wide marginal forest, but may extend inland to the very base of the bluffs, as at Hanover. It may then be divided into smaller areas by transverse belts of forest, as at Havana. To these smaller tracts local names are sometimes given, as Benton Prairie at Oquawka. The tracts thus delimited are not uniform, but each may be occupied by two or more consocies. The different prairies of a sand area are, however, occupied in general by the same consocies and have the same flora. But two noteworthy species seem to form an exception to this rule, *Brewcria Pickeringii* in Benton Prairie at Oquawka, and *Lesquerella argentea* in the Devil's Neck region of the Havana area.

The bunch-grasses which give the association its name produce at the base or along the lower portion of the culm a number of leaves, which are aggregated into loose or crowded bunches, depending upon their size and number. Rising from their center are the flowering culms, and beneath the living leaves are also the dried dead leaves and culms of the previous season. The height of the bunches, exclusive of the culms, is therefore, in most cases, approximately equal to the length of the basal and lower leaves. In simple bunches all the leaves and culms radiate from one center, and a bunch consists of one plant, or rather of one stool. The diameter of the bunch is then not more than twice the length of the basal leaves. Such simple bunches are exhibited by *Panicum perlongum* and *Stipa spartea*. With some other species, as *Panicum pseudopubescens,* the culms are also spreading or horizontal, and the diameter of the bunch is about equal to twice the length of the culms. In other cases the individual plants are closely associated, so that the dense bunches may reach any diameter, and are usually very irregular in shape. This

habit is well illustrated by *Leptoloma cognatum*. The bunches of each species are distinct in size, structure, and general appearance, and when in a sterile condition can frequently be recognized by their habit alone. Notes on the individual character of the bunches will follow.

The living and dead leaves of the bunches cover the ground in most cases so closely that other plants can not grow among them. The two bunch-forming sedges, *Carex Muhlenbergii* and *Cyperus Schweinitzii*, alone produce bunches so loose that various annuals usually grow within them. *Stipa spartea* also produces loose bunches through which *Ambrosia psilostachya* or *Teucrium occidentale* may grow. A number of small annuals may be found between the radiating culms of *Panicum pseudopubescens* at some distance from the center, while the dense compact bunches of *Koeleria cristata* and *Leptoloma cognatum* are entirely free from other plants.

Besides restricting the growth of other species, and thus retaining the dominance in the association, they act efficiently in preventing the blowing of the sand. The greater proportion of the surface is usually entirely covered, and the small intervening spaces are so narrow that the sand is not easily lifted by the wind above the bunches. The tendency to blow, if present, is usually shown by the slight elevation of the grasses above the concave or trough-shaped interspaces. Nevertheless, blowing may sometimes take place to such an extent that the whole association is destroyed, and succeeded by another in which *Panicum pseudopubescens* is the dominant grass, as will be described later. It seems probable that in most of these cases the density of the plant covering has been reduced by pasturing or other recent causes, or, conversely, that under strictly natural conditions the bunch-grasses permanently prevent blowing.

In some places the surface is entirely covered, either with bunch-grasses alone or with mat-plants in addition, and there is every gradation down to cases where but little more than half the actual surface is occupied. It may be arbitrarily assumed that the bunch-grass association can not exist with more than half the sand exposed, and it is certain that it may disappear with even more of the surface occupied. The proportion of the ground covered by the grasses varies with the species, the habitat, and the stability of the sand. Of the grasses which tend to cover a relatively small part of the surface *Koeleria cristata* and *Andropogon scoparius* are good examples, while the bunches of *Leptoloma cognatum* show especially a tendency to become confluent and to cover large unbroken areas. The consocies which contain the largest number of species of bunch-formers are also apt to occupy the space most completely.

The general appearance of the association, including especially the color-tone and number of secondary plants, depends almost entirely upon the specific peculiarities of the bunch-grasses represented and upon the density of the covering. Most bunches are so distinct in size, density, or other features that they are easily recognized, even when sterile. In doubtful cases minor morphological characters may be used, such as pubescence, the structure of the ligule, and other similar vegetative features. Some of the most important bunch-forming species are the following.

1. *Koeleria cristata.*—Bunches regular, compact, about one foot (3 dm.) in maximum diameter and eight inches (2 dm.) high, with a considerable accumulation of dead leaves beneath them, forming an elevated central tuft and radiating on the sand; leaves six to ten inches (15-25 cm.) long, mostly straight and erect, glaucous-green or canescent with fine pubescence.

The regular close bunches of *Koeleria* have an appearance of trimness and neatness in which they excel any other species. The gray-green color and the shining spikelike panicles make the grass very conspicuous, especially during the aestival aspect when it is in bloom, or at any season when the dew is still on it in the early morning. The bunches are rarely confluent and tend to leave a considerable uncovered area between, especially when not associated with other species.

2. *Leptoloma cognatum.*—Bunches 8-12 inches (20-30 cm.) wide and about eight inches (20 cm.) high, very compact, close and dense, flat-topped, frequently confluent in large irregular patches; leaves short, all erect or radiating, and freely mixed with the dead leaves of the preceding season, giving the whole bunch a yellow-gray appearance. The short leaves are more irregularly arranged than those of *Koeleria cristata*, and the dead leaves and culms remain for a long time mixed with the living. In the serotinal season the large, but very lax, red-flowered panicles appear and impart a distinct reddish hue to the consocies in which the plant grows.

3. *Stipa spartea.*—Bunches loose, few-leaved, but regular in size, 1-1.5 feet in diameter and about the same height, with a slight accumulation of dead leaves and culms on the sand beneath. The flowering culms rise to a height of three feet (1 m.). Of all the bunch-forming species of grass in the association this species forms the loosest and most indefinite bunches.

4. *Panicum pseudopubescens* (Pl. III, Fig. 2).—Bunches irregularly circular in outline, depressed, 1-1.5 feet (3-5 dm.) in diameter, four to six inches (1-1.5 dm.) high; culms and leaves radiating from

the center, straight, barely exceeding the dead culms with their split and curled leaves. The culms and especially the spikelets are red in color and give a reddish tone to the whole bunch.

This species forms one of the most distinctive bunches of the association, due to the depressed or prostrate radiating culms with their erect or almost appressed leaves, and to the persistence on the dead culms of the recurved leaves of the previous season. The culms extend beyond the leaves, and bear small, but conspicuous, panicles of red spikelets. This species is more characteristic of the association to which it gives its name, but is also frequent in the typical bunch-grass, where its peculiar habit makes it conspicuous.

5. *Bouteloua hirsuta.*—Bunches low, irregular, two to four inches (5-10 cm.) high, usually confluent in matlike masses 5-12 inches (1-3 dm.) in diameter; leaves short, irregular in position, forming a loose tuft, conspicuously gray-pubescent, and giving a gray color to the whole bunch. The slender culms, 4-12 inches (1-3 dm.) high, appear during the late aestival season. The small bunches are entirely too low to compete with the other grasses for space or to constitute a conspicuous element in the association. They are usually restricted to the intervening spaces, where they have the general habit of mats rather than of bunches. They associate frequently with *Selaginella rupestris.*

6. *Bouteloua curtipendula.*—Bunches loose, 6-12 inches (1-3 dm.) in diameter, eight to ten inches (2-3 dm.) high; leaves mostly all erect, six to eight inches (15-20 cm.) long.

7. *Cyperus Schweinitzii.*—Bunches very open and loose, basal leaves few in number, ascending; culms several, erect or ascending. The plant frequently has the habit of an interstitial rather than of a bunch-grass.

8. *Andropogon scoparius.*—Bunches one to three feet (3-8 dm.) wide, circular, 1-1.5 feet (3-4 dm.) high, compact, and regular; leaves very long and narrow, erect or ascending, the dead leaves persisting as a dense mass at the base, or recurved around the margin of the bunch; culms about two feet (6 dm.) high, the dead culms persisting through the following summer.

The bunches are notable for their large size and the dense mass of dead leaves mingled with the living ones. As the bunches grow older the center dies, and rings are formed which reach a maximum diameter of over a yard (1 m.). In such rings the zone of living grass is three to eight inches (1-2 dm.) wide, and the central portion is elevated four to six inches (10-15 cm.) above the general level. It is composed of a dense mass of old roots and culms mingled with

debris of all kinds, and is almost always devoid of any plant growth.

9. *Andropogon furcatus.*—The bunches of this grass, commonly known as bluejoint, resemble those of the smaller *A. scoparius* in general habit, but are taller, 1.5-2.5 feet (4-8 dm.), and frequently larger in diameter, three to four feet (8-12 dm.). The leaves are larger, less densely aggregated, and without the tangle of dead leaves among them. The flowering culms are three to five feet (10-15 dm.) tall or even more, and seldom persist until the following summer. Like *A. scoparius,* the bluejoint may also form rings by the death of the center of the old bunches. These are five to seven feet (15-20 dm.) in diameter and without a conspicuous elevated center.

Sorghastrum nutans and *Panicum virgatum* (Pl. IV, Fig. 2) form large bunches much resembling those of bluejoint. *Calamovilfa longifolia* grows in patches with the individual culms one to six inches (3-15 cm.) apart, forming dense clusters which resemble true bunches. *Eragrostis trichodes* produces bunches closely resembling those of *Andropogon scoparius* in general character, but without the mass of dead leaves. The bunches of *Panicum perlongum* are very regular, hemispherical in shape, and composed of a dense mass of straight radiating leaves. In general appearance they resemble the bunches of *Koeleria cristata. Paspalum setaceum* and *Eragrostis pectinacea* send up several culms from a common center, on which the leaves are most closely approximated near the base, thus forming a loose irregular bunch. The loose open bunches of *Carex Muhlenbergii* are especially characterized by their leafless, obliquely ascending stems.

Since the bunch-grasses virtually exclude other growth beneath them, the secondary species are found upon the small areas of bare sand between the bunches. They may be conveniently divided into four ecological groups based upon their habits and structure. As in most ecological classifications, these groups are not entirely distinct, and some species are of doubtful position. To them may be given the names perennials, mats, interstitials, and parasites.

The members of the first group, the perennials, are generally very deep-rooted, and frequently grow in tufts or bunches resembling those of the bunch-grasses. The deep roots are a response to the conditions of water supply, and the bushy habit is possibly correlated with the generally xerophytic environment and exposure to the wind. Resembling the bunch-grasses in habit, they are able to compete with them for space, and may be found in the center of a patch of grass, where they have persisted since the grass surrounded them. Their

competition with the bunch-grasses is defensive rather than offensive; they can resist the encroachment of a grass, but are not able to displace it. Some typical plants of this habit are *Aster linariifolius, Lithospermum Gmelini, Aster sericeus, Tephrosia virginiana* (Pl. IX, Fig. 1), and *Chrysopsis villosa.* Others have more slender stems, several of which arise from a common base and spread divergently, somewhat resembling in habit the looser bunches of *Carex Muhlenbergii* or *Cyperus Schweinitzii.* Good examples of this type are furnished by *Callirhoe triangulata, Petalostemum purpureum,* and *Petalostemum candidum.* Still others have erect stems which tend to grow in clusters, as *Coreopsis palmata, Solidago missouriensis, Solidago nemoralis, and Helianthemum majus.* A fourth type is furnished by *Physalis virginiana, Baptisia bracteata,* and *Tradescantia reflexa,* with solitary stems which branch freely or bear widely spreading leaves toward the top. A fifth type is illustrated by *Euphorbia corollata* or the species of *Liatris,* whose slender erect stems grow singly and occupy very little ground space. This type approaches most nearly the third group of interstitials. One member of the group, *Breweria Pickeringii,* has very numerous long decumbent stems, forming an elevated mass at the center, and spreading out in all directions on the sand.

The shrubs of the association are for convenience classified in this group. They include *Rhus canadensis,* var. *illinoensis,* forming dense rounded masses 3-15 feet (1-5 m.) across and three feet (1 m.) high, and excluding all other vegetation; *Amorpha canescens* and *Ceanothus americanus,* undershrubs with several erect or ascending stems one to three feet (3-8 dm.) high; and *Ceanothus ovatus* (Pl. II, Fig. 2), with several ascending stems forming an irregular bushy shrub two or three feet (1 m.) tall. The two species of *Ceanothus* are notable for their immense woody roots, frequently six inches (1.5 dm.) in diameter and extending downward to great depths. They are crowned by a few live stems, which are of comparatively short life, and with the dead and decaying bases of many others of previous years.

It is needless to say that the vast majority of these plants present obvious xerophytic adaptations, the most general of which are a reduction of surface to narrow or small leaves, and a protective covering of silvery or canescent hairs or scales. Their general tone is grayish green, amid which the vivid green of *Euphorbia corollata* and *Tradescantia reflexa* appears strangely out of place. The various types described do not include all the species of the group, but omit some of the less frequent. Neither do all perennials belong to this

group, but some, as *Lesquerella argentea,* are placed among the interstitials.

The second group includes the mat-plants, a small group with but three flowering plants, *Opuntia Rafinesquii, Opuntia fragilis,* and *Antennaria* sp. *Selaginella rupestris* is also common in the Hanover area. These grow close to the sand and tend to spread annually over a larger area. They are unable to encroach upon either the bunch-grasses or the perennials, and do not survive when covered by members of these groups. Their number is accordingly largest in the more open consocies. These plants are of the greatest importance in binding sand, and under certain conditions have a prominent part in stabilizing blowing sand. *Selaginella rupestris* is especially noteworthy for its habit of circular growth. Extending vegetatively from the center, its growth is so regular that a circular patch is formed. This is soon converted into a ring by the death of the center, leaving a marginal zone of living plants one to two inches (2-5 cm.) wide. This ring gradually increases in size until it may reach a maximum diameter of four feet (1.2 m.). Additional rings may begin within an old one, or parts of two rings may overlap. Megaspores are produced in enormous quantities, but their successful growth must be rare. The prickly pear, *Opuntia Rafinesquii,* is much more common in the Havana area than in any of the others. The mats of *Selaginella* are favorite places for small mats of a dark colored crusty species of *Cladonia.* Small mosses, of unidentified species, are also frequently found, and in many places a dark-colored crust on the sand is formed by a species of *Oscillatoria,* which from its habit may also be classified with the mats.

The third group, the interstitials, is composed in general of annuals, with slender, frequently unbranched stems, generally narrow leaves, and fibrous roots. They come up late, principally during the season of heavy rainfall in June or July, and cover the bare areas of sand with prodigious numbers of individuals. Notwithstanding their number, they are of the least ecological importance. Their slender stems occupy little space and take no part in sand-binding, while the very existence of the entire group is due to the presence of the bunch-grasses, which act as windbreaks and hold the sand. If the number of grasses decreases somewhat, there is a correspondingly larger number of interstitials, but if the bare spots become too large, so that blowing of the sand begins, their number begins to decrease.

The most abundant species of interstitials are *Oenothera rhombipetala, Ambrosia psilostachya, Linaria canadensis, Cassia Chamaechrista, Monarda punctata,* and *Croton glandulosus,* var. *septentrionalis.*

The fourth group, or parasites, is represented by a single species of seed plant, *Orobanche fasciculata,* found on the roots of *Artemisia caudata* in the Hanover area.

While these four groups are sufficiently distinct to serve as ecological units, they are not absolutely separate. The perennial *Lespedeza capitata,* with its slender stems and narrow leaves, associates frequently with the true interstitials, and might then well be regarded as one of them. *Cyperus Schweinitzii* appears now as a bunch-grass, now as an interstitial. *Bouteloua hirsuta* behaves sometimes as a bunch-grass, producing small tufts two to four inches (5-10 cm.) high, but frequently it functions more as a mat and associates with *Selaginella rupestris* and *Antennaria* sp., or, when growing between larger bunches of *Koeleria cristata,* it might be regarded also as an interstitial.

The number of secondary species and individuals is naturally greatest in the more open parts of the association and least in the denser portions. The mats may entirely disappear and the interstitials be greatly reduced in number when the bunch-grasses are closely aggregated. The perennials, with their greater resistance to crowding by the grasses, remain throughout and always occupy a prominent place in the association. The close relation between the secondary and dominant plants of an association is seldom better illustrated than in this one, where the presence and disappearance of the interstitials are both correlated with the density and luxuriance of the bunch-grasses.

The association as a whole is, as already noted, divided into a number of consocies. Some of these are characterized by a single species of grass and may be called pure consocies. Such are those characterized by *Koeleria cristata, Leptoloma cognatum, Stipa spartea,* and *Carex Muhlenbergii.* A larger part of the association is occupied by several characteristic species and is here termed the mixed consocies. Although the specific composition of the latter varies somewhat from place to place, its general appearance is so uniform that it does not admit of further subdivision. Besides describing these five, representing natural conditions, it is necessary also to mention some of the effects of cultivation, pasturing, and burning. The consocies are described in the reverse order of their importance, and the notes on cultural changes follow. It will be observed that the floristic differences between the various consocies are slight.

The Carex Muhlenbergii Consocies

The only observed examples of this consocies were in the Hanover area, the first in an interdunal depression, the second on the

side of a gentle slope. In both cases they were surrounded by other consocies of the same association, but were sharply separated from them.

The dominant species is *Carex Muhlenbergii.* The bunches are separate or rarely confluent and cover about three fourths of the surface. Since there are few dead leaves beneath the bunches, and the living leaves are mainly erect, there is abundant space for other plants. Although four species of grasses are included, of which three are typical bunch-grasses, they are so sparsely represented that none can at any place be considered dominant. The following secondary species were noted.

Bunch-grasses:

Leptoloma cognatum
Panicum virgatum
Panicum pseudopubescens
Poa pratensis

Perennials:

Lithospermum Gmelini
Pentstemon hirsutus
Solidago nemoralis
Helianthus scaberrimus
Helianthus occidentalis

Mat:

Opuntia Rafinesquii

Interstitials:

Monarda punctata
Linaria canadensis
Ambrosia psilostachya
Lactuca canadensis

The vernal aspect is characterized by *Lithospermum Gmelini,* the serotinal by *Monarda punctata,* and the autumnal by *Helianthus occidentalis.* The whole consocies stands out in sharp relief from its surroundings because of the rich dark-green color of the dominant species.

Carex Muhlenbergii is also widely distributed throughout the bunch-grass association, and occasionally appears in large numbers on the lee deposits of blowouts, and may take part in their stabilization. That the consocies does not have this origin is shown by the absence of *Diodia teres* and *Tephrosia virginiana,* the poor development of *Panicum virgatum,* and the presence of *Opuntia Rafinesquii.*

The Stipa spartea Consocies

This consocies is developed in but one place in the Hanover area, and is there of limited extent.

Stipa spartea is the dominant grass, with *Poa pratensis* second in abundance. The bunches of *Stipa* are here more or less confluent, and the intervening spaces are so occupied by blue-grass that the surface of the sand is completely covered. This leaves no opportunity for the growth of the usual interstitial plants and also tends to limit the number of perennials. But four species occur and they are represented by few individuals. They are *Panicum pseudopubescens, Callirhoe triangulata, Coreopsis palmata,* and *Aster linariifolius.* All of these are common in other consocies of the same association.

At either side the consocies changes rather abruptly into another characterized by *Koeleria cristata,* which has larger open spaces between the bunches and permits the growth of more secondary species.

The Koeleria cristata Consocies

In the Hanover area this is by far the most important consocies of the bunch-grass association which is characterized by a single species, and in area is second only to the mixed consocies. If its present extent may be taken as an index, it must originally have covered hundreds of acres of the sand prairie, although in scattered patches of rather small size. It is found alike on the sides and tops of the hills, but seldom in the depressions between them. Elsewhere the consocies was not observed.

The dominant species is *Koeleria cristata.* The bunches of this grass are mostly separate and compact, occupying from one half to two thirds of the surface. The dead basal leaves cover the sand between the bunches, and make an efficient protection against blowing. *Panicum pseudopubescens,* which flourishes where the sand is largely bare, is also frequently well developed.

The number of secondary plants is large because of the unusual amount of ground space available, and comparatively many species are represented. The number of individuals of the interstitial species is especially large. The mats of *Selaginella rupestris* reach here their maximum size; regular circles up to three feet (1 m.) in diameter are common, and they may become confluent to form solid masses eight to ten feet (2-3 m.) wide. *Koeleria cristata* lives indiscriminately upon these mats or between them, and so do most of the perennials. *Panicum pseudopubescens* and the annuals are seldom found except on the bare sand between them. The centers of the *Selaginella* mats are usually covered with a black crust, upon which a species of *Cladonia* is frequently growing. *Antennaria* sp. may grow on the mats also, or in the absence of *Selaginella* form

circular patches one to three feet (3-10 dm.) across, which are very conspicuous because of their gray color. The principal secondary species are the following.

Bunch-grasses:

Sorghastrum nutans
Panicum virgatum
Panicum pseudopubescens
Panicum perlongum
Stipa spartea

Perennials:

Tradescantia reflexa
Amorpha canescens
Petalostemum candidum
Petalostemum purpureum
Tephrosia virginiana
Viola pedata
Callirhoe triangulata
Lithospermum Gmelini
Pentstemon hirsutus
Solidago nemoralis
Aster sericeus
Aster linariifolius
Helianthus scaberrimus
Coreopsis palmata
Artemisia caudata

Mats:

Selaginella rupestris
Opuntia Rafinesquii
Opuntia fragilis
Antennaria sp.

Interstitials:

Festuca octoflora
Rumex Acetosella
Lepidium virginicum
Arabis lyrata
Oxalis corniculata
Scutellaria parvula
Monarda punctata
Ambrosia psilostachya

The vernal aspect is characterized by the blue flowers of *Viola pedata,* which were still in bloom when the consocies was first visited in June; later, *Pentstemon hirsutus* and *Lithospermum Gmelini* are conspicuous with their white and yellow flowers. The aestival season is well markd by *Tradescantia reflexa,* and the serotinal by *Monarda punctata,* which is frequently present in immense numbers. The flowers of the prairie clovers (*Petalostemum*), the lead plant (*Amorpha canescens*), and the sand poppy (*Callirhoe*) appear at the same season, but the plants are usually too scattered to break the effect of the masses of *Monarda.* Still later, in the autumnal aspect, the prevailing tone is yellow from the flowers of the goldenrod, *Solidago nemoralis.*

The *Koeleria cristata* consocies illustrates well the general principle that an association may be derived from different sources. In

some cases it is evidently the result of the stabilization of the *Panicum pseudopubescens* association, in which event it is characterized by the greater abundance of that species, the better development of mats, which are composed of *Selaginella* rather than *Antennaria,* and the greater abundance of *Scutellaria parvula* and *Arabis lyrata.* In other cases it is entirely independent of any former blow conditions, and then contains less *Panicum pseudopubescens,* mats of *Antennaria* rather than *Selaginella,* and a larger proportion of perennials, including *Aster sericeus* and *Amorpha canescens,* which are absent on blowing sand. The two types have the same structure and represent the same consocies, notwithstanding their difference in species. The only ecological difference between them, aside from their origin, is their age, and it may very properly be considered that the floral difference will gradually disappear as the various perennials succeed in establishing themselves in the younger type. The order of appearance of the species in this process of stabilization will be considered later.

There is usually a gradual change in the appearance of the consocies at its margin as other grasses appear or as *Koeleria* disappears. The secondary species vary but little specifically, but the number of individuals naturally increases or decreases according to the density of the grasses.

The Leptoloma cognatum Consocies

This consocies is extensively developed in the Hanover, the Dixon, and the Oquawka areas, and in the last two is by far the most important consocies characterized by a single species (Pl. I, Fig. 2). In the Hanover area it is exceeded in extent by the *Koeleria cristata* and the mixed consocies. It has a wider topographic range than the *Koeleria cristata* consocies, and is found in the interdunal depressions as well as on the hilltops.

Leptoloma cognatum is the principal bunch-forming grass, and its flat-topped bunches are usually so confluent that nine tenths of the surface or more is occupied. The bunches are of such uniform height and density that the consocies appears as if artificially trimmed, and has a generally gray-green color because of the numerous dead leaves mixed with the living. The other grasses, which are usually of larger size and bright green in color, stand out very prominently against the background. In the serotinal aspect the plants are in bloom, and the large panicles with the red spikelets are so numerous that the whole consocies has a reddish hue. A few other grasses may at some places occupy enough of the surface to affect the general appearance of the consocies. They are *Koeleria cristata* at Han-

over and Dixon, *Sorghastrum nutans* at Hanover, *Panicum pseudopubescens* at Hanover, *Andropogon scoparius* at Dixon and Oquawka, and *Paspalum setaceum* at Oquawka. At Dixon, *Chrysopsis villosa* becomes conspicuous and occupies a large amount of space, but it seems probable that the conditions there are not quite normal.

It has already been noted that the confluent habit of the bunches of *Leptoloma cognatum* restricts the space for secondary species. The great extent of the consocies, on the other hand, tends to increase the number of species, even though the number of individuals is relatively small. A list of the secondary species follows.

Bunch-grasses:

Andropogon scoparius
Sorghastrum nutans
Paspalum setaceum
Panicum perlongum
Panicum Scribnerianum
Panicum pseudopubescens
Koeleria cristata
Bouteloua hirsuta
Bouteloua curtipendula
Poa pratensis
Cyperus Schweinitzii
Carex umbellata
Carex Muhlenbergii

Perennials:

Tradescantia reflexa
Sisyrinchium sp.
Oxybaphus nyctagineus
Delphinium Penardi
Baptisia bracteata
Amorpha canescens
Petalostemum purpureum
Tephrosia virginiana
Lespedeza capitata
Polygala polygama
Euphorbia corollata
Rhus canadensis, var. *illinoensis*
Ceanothus americanus
Callirhoe triangulata
Helianthemum majus
Viola pedata
Asclepias amplexicaulis
Acerates viridiflora
Acerates viridiflora, var. *lanceolata*
Lithospermum Gmelini
Verbena stricta
Verbascum Thapsus
Pentstemon hirsutus
Ruellia ciliosa
Liatris scariosa
Chrysopsis villosa
Solidago speciosa, var. *angustata*
Solidago nemoralis
Aster linariifolius
Helianthus scaberrimus
Achillea Millefolium

Mats:

Selaginella rupestris
Opuntia Rafinesquii
Antennaria sp.
Senecio Balsamitae

Interstitials:

Festuca octoflora
Cyperus filiculmis
Rumex Acetosella
Polygonum tenue
Silene antirrhina
Arabis lyrata
Lepidium virginicum
Cassia Chamaechrista
Linum sulcatum
Polygala incarnata
Croton glandulosus, var. *septentrionalis*
Oenothera rhombipetala
Monarda punctata
Hedeoma hispida
Linaria canadensis
Specularia perfoliata
Erigeron annuus
Erigeron ramosus
Ambrosia psilostachya

Of the grasses in the above list, *Bouteloua hirsuta* is most abundant in the Oquawka area, and may usually be found in any of the narrow strips of sand between the bunches of *Leptoloma*, although its small size makes it very inconspicuous. Near Hanover, *Bouteloua* does not occur in this consocies, and *Panicum Scribnerianum* and *Panicum perlongum* are important secondary species. The others are usually infrequent but are sometimes very conspicuous if the bunches are of large size and overtop the *Leptoloma*. Those of *Andropogon scoparius* and *Carex Muhlenbergii* contrast especially with *Leptoloma* both in size and color.

In the Hanover area the most abundant perennials are *Euphorbia corollata* and *Helianthus scaberrimus*; in the Oquawka area, *Ruellia ciliosa* and *Baptisia bracteata*. Many of the perennials are conspicuously taller than the *Leptoloma* and stand out in prominent relief above it. This is especially true of the bushy shrubs *Ceanothus americanus*, *Rhus canadensis*, var. *illinoensis*, and *Amorpha canescens*.

Antennaria is the most abundant mat, and is frequent throughout the consocies. The mats are small because of the limited space available. *Senecio Balsamitae* forms dense patches two to three feet (5-10 dm.) across and shows some tendency to resist the encroachment of the bunch-grasses.

Of the interstitial plants, *Ambrosia psilostachya* is omnipresent, and is represented by an immense number of individuals. *Rumex Acetosella* and *Monarda punctata* are also very abundant. The latter is one of the most conspicuous features of the serotinal aspect. *Oenothera rhombipetala* is not so abundant as *Monarda*, but is equally conspicuous at its blooming season during the aestival aspect, because of its taller stems and vivid yellow flowers. The other interstitial plants vary greatly from place to place, and almost any

species may in some places or at some seasons appear very conspicuously. A striking example of this was given by *Linum sulcatum*, which was observed only on one sand-hill near Oquawka, and was so local that it did not appear in any of the quantitative studies made there. The plant has very slender erect unbranched stems, and during the first days of July was hardly noticeable. A few days later the flowers appeared and brought the plant at once so much into evidence that it might have been wrongly considered a characteristic member of the consocies.

TABLE I.—FLORISTIC COMPOSITION OF TEN QUADRATS IN THE *Leptoloma cognatum* CONSOCIES, OQUAWKA AREA.

Leptoloma cognatum	X	X	X	X	X	X	X	X	X	X
Paspalum setaceum	X	X	-	X	X	X	-	X	X	-
Panicum Scribnerianum	-	X	-	-	-	X	X	-	-	-
Bouteloua hirsuta	X	X	-	X	X	X	-	X	X	X
Cyperus filiculmis	-	-	-	-	-	-	-	X	X	-
Carex Muhlenbergii	-	-	-	-	-	-	-	-	X	-
Rumex Acetosella	-	X	X	X	X	-	X	X	X	X
Polygonum tenue	-	-	-	-	-	X	-	-	-	X
Silene antirrhina	-	-	X	-	-	-	X	-	-	-
Cassia Chamaechrista	-	X	X	X	-	-	X	X	-	-
Baptisia bracteata	X	X	X	-	X	-	-	X	-	X
Amorpha canescens	-	X	X	-	X	-	-	-	-	X
Polygala incarnata	X	-	-	-	-	-	-	-	-	-
Oenothera rhombipetala	-	-	-	X	-	-	X	-	-	X
Verbena stricta	X	X	-	X	-	-	X	X	X	-
Monarda punctata	X	-	X	X	-	X	X	-	-	X
Hedeoma hispida	-	-	-	-	-	-	X	-	X	-
Linaria canadensis	-	-	X	-	-	-	-	-	-	-
Pentstemon hirsutus	-	-	-	-	-	X	-	-	X	-
Ruellia ciliosa	X	X	X	X	X	X	X	X	X	X
Specularia perfoliata	-	X	-	-	-	-	-	-	-	-
Erigeron ramosus	-	-	-	X	X	X	X	-	-	X
Antennaria sp.	-	X	-	-	-	-	-	-	-	-
Ambrosia psilostachya	X	X	-	X	X	X	X	X	X	X
Senecio Balsamitae	-	-	-	-	-	-	X	-	-	-

A series of counts (Table I) were made at Oquawka, in the best example of the consocies observed (near the site of Plate I, Fig. 2), to determine the relative frequency of the secondary species. These counts record the presence or absence of the species in each of ten quadrats two meters square, extending in a continuous strip through

the consocies. No record was made concerning the abundance of each species.

Bouteloua hirsuta, Ruellia ciliosa, Ambrosia psilostachya, and *Rumex Acetosella* appear as the most frequent of the secondary species, while *Leptoloma cognatum* naturally appears in every quadrat. The average number of species in each quadrat is 10.6, while the whole number observed in the Oquawka area is 47.

The consocies was not under observation during the vernal season, but *Baptisia bracteata* and *Delphinium Penardi* are probably quite conspicuous at that time. During the aestival aspect of late June and July *Oenothera rhombipetala* and *Amorpha canescens* are much in evidence. These are followed in August by *Monarda punctata,* and the red spikelets of *Leptoloma cognatum* are also very conspicuous at that season. In the Hanover area the vernal aspect is characterized by *Pentstemon hirsutus,* while the aestival and serotinal conditions are essentially the same as at Oquawka.

In the Oquawka area contact between this consocies and others was not observed. At Hanover it grades into the mixed consocies next to be described. There is no sharp line between the two, but other species of grasses appear, the spaces between the bunches become wider, and a greater number of secondary species occupy the bare sand thus available.

The Mixed Consocies

In the Hanover area the greatest portion of the sand prairie was originally occupied by a mixed consocies, in which several species of bunch-grass were well represented (Pl. II; Pl. III, Fig. 1). The same consocies was also of considerable importance in the Havana area, and was described in a former paper (Hart and Gleason, *1907:* 158-160). It was also well represented in the Oquawka area, especially in the prairies between Keithsburg and Oquawka. In the Dixon area no estimate can be made at present concerning its former extent. It seems probable that over the sand prairies as a whole at least two thirds of the surface was occupied by this mixed growth. Although now greatly reduced in area because of cultivation, the remnants left show that it grew alike on the higher elevations and on the depressions between the hills; that there was little difference in the vegetation as the habitat changed; and that the specific composition of the grasses varied considerably from place to place, but that the general appearance of the consocies was remarkably uniform.

The reason for its wide extent is obvious. The bunch-grasses all belong to the same ecological type, and, with the unimportant exception of *Boutcloua hirsuta,* have approximately the same size. Competition between them therefore is largely limited to a struggle for ground space, and of that there is usually an abundance. There is very little possibility of one species shutting off the light from another, either by its size or by making an earlier start in the season. The dead leaves and culms with which each bunch is surrounded make a good ground cover which holds the sand and excludes the growth of seedlings of competing species. None of the species is distinguished by a particularly large seed production or by special adaptations for seed dispersal. Few of them spread by underground stems. Taking all these points into consideration, it is clear that there are no particular adaptations which might lead to a monopoly by one species in the consocies. The presence of so many species indiscriminately mixed is caused by their uniform dissemination and continued by the evenness of their competition for space. For a few species these statements do not hold. The small bunches of *Boutcloua hirsuta* and the flat ones of *Panicum pseudopubscens* are easily overshadowed and killed by the growth of other species. The loose, few-leaved bunches of *Stipa spartea* similarly tend to be crowded out by species of denser habit. These three species, accordingly, are not to be found throughout the consocies, but tend to disappear as the surface becomes more completely covered.

The number of grasses which occur is large, and includes virtually every species of bunch-grass found in the region. Not all of them occur together, or even in the same area, but in most places three or four may be recognized as of chief importance, while the others have more of the nature of secondary species. The following bunch-grasses were observed:

**Andropogon scoparius*
**Andropogon furcatus*
Sorghastrum nutans
**Leptoloma cognatum*
Paspalum setaceum
**Panicum virgatum*
Panicum perlongum
Panicum Scribnerianum
**Panicum pseudopubescens*
**Stipa spartea*
Calamovilfa longifolia
**Koeleria cristata*
**Boutcloua hirsuta*
**Boutcloua curtipendula*
Eragrostis trichodes
**Eragrostis pectinacea*
Poa pratensis
**Cyperus Schweinitzii*
Carex umbellata
Carex Muhlenbergii

Of these twenty species, eleven, marked with an asterisk, have been noted in some locality as dominant species, that is, so abundant

and occupying so much space that their removal would seriously change the nature and appearance of the consocies. A further study shows that three species are so regularly present and so frequently associated with each other that they may be regarded as the most typical grasses of the consocies. They are *Leptoloma cognatum, Koeleria cristata,* and *Andropogon scoparius.* The remaining nine grasses are always secondary species and never occupy a considerable portion of the ground space. Their huge bunches, as of *Sorghastrum nutans,* or tall culms, as of *Calamovilfa longifolia,* may nevertheless make them very conspicuous in some places. A few other grasses, not bunch-formers, are also mentioned under the proper head.

There is a great variety of perennials, interstitials, and a few mats, of which the following were listed.

Perennials:

Equisetum hyemale, var. *intermedium*
Tradescantia reflexa
Sisyrinchium sp.
Anemone cylindrica
Baptisia bracteata
Amorpha canescens
Petalostemum purpureum
Petalostemum candidum
Tephrosia virginiana
Lespedeza capitata
Polygala polygama
Euphorbia corollata
Rhus canadensis, var. *illinoensis*
Ceanothus americanus
Ceanothus ovatus
Callirhoe triangulata
Helianthemum majus
Viola pedata
Asclepias amplexicaulis
Acerates viridiflora
Acerates viridiflora, var. *lanceolata*
Brewcria Pickeringii
Phlox bifida
Lithospermum Gmelini
Verbena stricta
Physostegia denticulata
Physalis virginiana
Physalis heterophylla
Pentstemon grandiflorus
Pentstemon hirsutus
Synthyris Bullii
Kuhnia eupatorioides, var. *corymbulosa*
Liatris cylindracea
Liatris scariosa
Chrysopsis villosa
Solidago speciosa, var. *angustata*
Solidago nemoralis
Solidago missouriensis
Solidago rigida
Aster sericeus
Aster multiflorus
Aster linariifolius
Aster sp.
Brauneria pallida
Helianthus scaberrimus
Helianthus occidentalis
Coreopsis palmata
Achillea Millefolium
Artemisia caudata

Interstitials:

Aristida tuberculosa
Festuca octoflora
Elymus virginicus
Cyperus filiculmis
Stenophyllus capillaris
Carex pennsylvanica
Carex festucacea, var. *brevior*
Commelina virginica
Polygonum tenue
Chenopodium album
Froelichia floridana
Mollugo verticillata
Silene antirrhina
Talinum rugospermum
Lesquerella argentea
Lepidium virginicum
Erysimum parviflorum
Arabis lyrata
Cassia Chamaechrista
Strophostyles sp.
Linum sulcatum
Polygala verticillata
Croton glandulosus, var. *septentrionalis*
Crotonopsis linearis
Euphorbia Geyeri
Oenothera rhombipetala
Verbena bracteosa
Monarda punctata
Hedeoma hispida
Linaria canadensis
Specularia perfoliata
Erigeron ramosus
Erigeron canadensis
Gnaphalium polycephalum
Ambrosia psilostachya
Lactuca canadensis

Mats:

Selaginella rupestris
Opuntia Rafinesquii
Antennaria sp.

Parasite:

Orobanche fasciculata

Not every station of the consocies contains all of these secondary species, or even a majority of them. The actual specific composition of the consocies and the frequence and abundance of the species vary so greatly from place to place that individual descriptions must be given. Seven distinct areas occupied by the mixed consocies were examined with more or less detail.

1. Hanover area, one mile southwest of the railway station. The consocies occupies a flat interdunal depression (Pl. III, Fig. 1). Nine species of bunch-grasses are present, which are named in the approximate order of their abundance: *Leptoloma cognatum, Koeleria cristata, Stipa spartea, Sorghastrum nutans, Panicum perlongum, Panicum Scribnerianum, Carex Muhlenbergii, Panicum pseudopubescens,* and *Bouteloua hirsuta.* Of these the first two occupy more space than the other seven together. The bunches are very compact and close and at a little distance resemble a close sod. Many dead leaves

collect under the bunches, aiding in the soil formation, and even the narrow strips between the bunches are frequently covered with dead leaves. On the small open spots are mats of *Antennaria* sp. and *Selaginella rupestris,* often growing together, and as the *Selaginella* dies out in the middle of the mats a brownish moss comes in. The result is that there is absolutely no chance for the sand to blow and humus can form rapidly. The surface sand is dark brown in color, somewhat loamy in texture, and partially coherent because of the mass of rootlets in it. This condition continues to a depth exceeding ten inches (25 cm.). Of the grasses mentioned, *Panicum pseudopubescens,* often so abundant in the consocies, is quite scarce, because of the absence of flat bare sand areas on which its decumbent bunches may spread. *Bouteloua hirsuta* is also scarce for the same reason. It grows in small tufts two to four inches (5-10 cm.) high on the mats of *Selaginella.* The presence of *Panicum Scribnerianum* is of interest, since it occurs only in the densest growth of bunchgrass. Thirty-one secondary species occur in various degrees of frequency. Ten quadrats of four square meters each were examined, and the numeral following each plant name indicates the number of quadrats in which the species occurred. Eleven species, without numbers, did not appear in the quadrats, but were found elsewhere in the consocies. The secondary species are as follows.

Perennials:

Equisetum hyemale, var. *intermedium* (2)
Poa pratensis
Petalostemum purpureum (1)
Tephrosia virginiana (4)
Polygala polygama
Euphorbia corollata (4)
Viola pedata (1)
Callirhoe triangulata (7)
Lithospermum Gmelini (2)
Acerates viridiflora, var. *lanceolata* (1)
Physalis virginiana
Aster sericeus (1)
Aster linariifolius (8)
Aster sp.
Helianthus scaberrimus (6)
Coreopsis palmata (2)
Artemisia caudata (1)

Mats:

Selaginella rupestris (8)
Opuntia Rafinesquii (1)
Antennaria sp. (6)

Interstitials:

Festuca octoflora
Chenopodium album
Arabis lyrata (1)
Hedeoma hispida
Linaria canadensis
Specularia perfoliata

Oenothera rhombipetala (1) *Erigeron ramosus*
Verbena bracteosa *Ambrosia psilostachya* (9)
Monarda punctata (4)

It may be noticed that of the twenty species appearing in the quadrats only four were interstitials, while of the eleven more infrequent species not appearing in the quadrats seven were interstitials. The relative frequency of the perennials is as 172 to 100. This illustrates and substantiates the general principle that the number of individuals of interstitial plants decreases as the density of the bunchgrass increases. Although *Ambrosia psilostachya* has a greater frequency than any of the perennials, it actually plays a very unimportant part in the consocies. Growing up straight and slender, it is quite inconspicuous and really much less important than *Aster linariifolius*. The high frequency of the latter species and of *Callirhoe triangulata* is also of interest

2. Hanover area; up the hill (Pl. III, Fig. 1) toward the plateau at the southwest of the station just described. The consocies continues without interruption, but is somewhat different in appearance (Pl. II, Figs. 1, 2). On the hillside the dominant species are the same, but *Panicum Scribnerianum* and *Selaginella rupestris* disappear; the mats of *Antennaria* are sparse; the ground is not well covered and does not have the loamy texture of the sand in the depression. *Bouteloua hirsuta* becomes more abundant, corresponding to the larger surface of open sand, and *Linaria canadensis*, an interstitial, is common with it. The remaining secondary species are almost the same as in the valley. A transect up this hillside is shown in Table II. The table shows that the change from the lower (left) end of the transect to the upper is caused chiefly by the addition of species as the space between the bunches becomes larger. In the first half the average number of species per quadrat of 0.25 sq. m. is 2.5, while in the last half it is increased to 4.35.

TABLE II.—TRANSECT OF 40 QUADRATS, EACH 5 DM. SQUARE, THROUGH THE MIXED CONSOCIES, HANOVER AREA.

| | | |

On the top of the hill there is again a little *Selaginella,* but the areas between the bunches are mostly bare or with *Bouteloua,* here growing in short flat irregular tufts. *Andropogon scoparius* appears in great abundance and becomes the most conspicuous member of the consocies. Frequency counts were made here also, as indicated by the numerals following the names. The ten bunch-grasses present are as follows:

Andropogon scoparius (10)
Sorghastrum nutans
Leptoloma cognatum (7)
Panicum perlongum (1)
Panicum Scribnerianum
Panicum pseudopubescens (10)
Stipa spartea
Bouteloua hirsuta (10)
Koeleria cristata (10)
Carex Muhlenbergii

Of these *Andropogon scoparius, Leptoloma cognatum,* and *Koeleria cristata* are the most important and are almost equally abundant. The flat bunches of *Panicum pseudopubescens* are very numerous, but are inconspicuous among the larger bunches of the other taller grasses.

The ground is open, with probably 20 per cent. of the surface exposed. The intervening spaces are bare or sparsely covered with dead stems and leaves, or rarely with mats of *Selaginella.* This permits a larger development of *Panicum pseudopubescens* and the interstitial vegetation, and the counts show that six of the seven interstitials are frequent enough to appear in one or more of the plots. Although the location is on top of a hill there is no evidence of blowing. The secondary species are as follows.

Perennials:

Carex festucacea, var. *brevior*
Tradescantia reflexa
Petalostemum purpureum
Lespedeza capitata (1)
Euphorbia corollata (1)
Ceanothus ovatus
Callirhoe triangulata (4)
Helianthemum majus
Viola pedata
Acerates viridiflora, var. *lanceolata*
Lithospermum Gmelini (2)
Aster sericeus (3)
Aster linariifolius (6)
Solidago nemoralis (4)
Helianthus scaberrimus (4)
Coreopsis palmata
Artemisia caudata (1)

Mats:

Selaginella rupestris (1)
Opuntia Rafinesquii

Interstitials:

Festuca octoflora (1)
Arabis lyrata
Oenothera rhombipetala (1)
Monarda punctata (3)
Linaria canadensis (4)
Erigeron ramosus (1)
Ambrosia psilostachya (9)

The relative frequency of perennials and interstitials is 56 to 100.

3. Oquawka area; a small tract of bunch-grass near the station at Milroy. The dominant vegetation consists of four grasses, almost equally abundant: *Koeleria cristata, Andropogon furcatus, Bouteloua curtipendula,* and *Bouteloua hirsuta.* Four other grasses are also present: *Stipa spartea, Panicum pseudopubescens, Panicum Scribnerianum,* and *Andropogon scoparius.* Other secondary species are as follows.

Perennials:

Tradescantia reflexa
Tephrosia virginiana
Lespedeza capitata
Euphorbia corollata
Rhus canadensis, var. *illinoensis*
Acerates viridiflora
Pentstemon hirsutus
Liatris scariosa
Solidago speciosa, var. *angustata*
Solidago nemoralis
Helianthus scaberrimus
Coreopsis palmata

Mat:

Opuntia Rafinesquii

Interstitials:

Cyperus filiculmis
Froelichia floridana
Lepidium virginicum
Cassia Chamaechrista
Polygala verticillata
Croton glandulosus, var. *septentrionalis*
Monarda punctata
Linaria canadensis
Ambrosia psilostachya

The ground here is open and has probably been used at times for pasture. This accounts for the large number of interstitial plants present. The same consocies extends also along the railway right of way, where several additional species occur, including the following.

Bunch-grass:

Elymus canadensis

Perennials:

Carex pennsylvanica
Carex festucacea, var. *brevior*
Sisyrinchium sp.
Anemone cylindrica
Amorpha canescens
Ceanothus americanus
Helianthemum majus
Asclepias amplexicaulis
Brewcria Pickeringii
Verbena stricta
Physostegia denticulata
Pentstemon grandiflorus
Aster sericeus
Aster multiflorus
Brauneria pallida
Achillea Millefolium

Interstitials:

Stenophyllus capillaris
Commelina virginica
Polygonum tenue

4. Oquawka area; nearly original bunch-grass near the county line between Henderson and Mercer counties. The dominant species are *Andropogon scoparius, Koeleria cristata*, and *Leptoloma cognatum*, named in order of their abundance. These three species are mixed indiscriminately and with them are several other bunch-grasses of less importance in the consocies. These are *Panicum pseudopubescens, Panicum virgatum, Panicum Scribnerianum, Andropogon furcatus, Bouteloua hirsuta*, and *Carex Muhlenbergii.*

The ground is about 90 per cent. covered, and the spaces between the bunches are well covered with patches of moss, mats of *Antennaria*, and bunches of *Panicum pseudopubescens* and *Bouteloua hirsuta.* The secondary species are the following.

Perennials:

Tradescantia reflexa
Baptisia bracteata
Amorpha canescens
Tephrosia virginiana
Lespedeza capitata
Euphorbia corollata
Acerates viridiflora
Rhus canadensis, var. *illinoensis*
Physalis virginiana
Helianthus scaberrimus
Helianthus occidentalis
Brauneria pallida

Mat:

Antennaria sp.

Interstitials:

Paspalum setaceum
Cyperus filiculmis
Commelina virginica
Silene antirrhina
Cassia Chamaechrista
Oenothera rhombipetala
Monarda punctata
Linaria canadensis
Specularia perfoliata
Ambrosia psilostachya

During the aestival aspect the blue spikes of *Amorpha canescens,* the pink heads of *Brauneria pallida,* and the yellow flowers of *Oenothera rhombipetala* are very conspicuous. *Lespedeza capitata* is especially abundant near the railroad, where the ground has been somewhat disturbed.

5. Havana area; on "Tower Hill", four miles (6 km.) north of Topeka. *Leptoloma cognatum, Eragrostis pectinacea,* and *Bouteloua hirsuta* are the dominant species. These occupy about equal amounts of space, but the *Bouteloua* is of course relatively inconspicuous. Associated with the grasses are twelve secondary species, as follows.

Perennials:

Tephrosia virginiana
Callirhoe triangulata
Phlox bifida
Pentstemon hirsutus
Liatris scariosa
Aster sericeus
Aster linariifolius

Mats:

Opuntia Rafinesquii
Antennaria sp.

Interstitials:

Silene antirrhina
Lesquerella argentea
Cassia Chamaechrista
Crotonopsis linearis
Oenothera rhombipetala

6. Havana area; the "Devil's Neck", three miles (5 km.) north of Topeka. The bunches are rather widely scattered, leaving a considerable portion of the ground space exposed. They are formed by *Leptoloma cognatum, Cyperus Schweinitzii,* and *Panicum pseudopubescens.* The latter is most abundant in the more open spots, indicating the approach of blow conditions. But three species of perennials are present, *Tephrosia virginiana, Callirhoe triangulata,* and a few plants of *Lespedeza capitata.* Scattered mats of *Opuntia Rafinesquii* occur. The interstitial plants are numerous, corresponding to the large space available, and consist of *Aristida tuberculosa, Ambrosia psilostachya, Crotonopsis linearis, Commelina virginica, Oenothera rhombipetala, Mollugo verticillata, Cassia Chamaechrista,* and *Strophostyles helvola.* The consocies here represents the last stage before succession by the *Panicum pseudopubescens* association, and is probably also somewhat modified by pasturing.

7. Dixon area; in a field near the railroad. The ground is more or less carpeted with fine cinders discharged from locomotives. The vegetation consists of large bunches of *Andropogon furcatus,* with

smaller ones of *Andropogon scoparius, Panicum virgatum, Leptoloma cognatum,* and some *Paspalum setaceum.* Other less important species of bunch-grasses are *Stipa spartea, Cyperus Schweinitzii, Panicum pseudopubescens,* and *Koeleria cristata,* indicating a former luxuriant development of the consocies. There are also scattered plants of *Froelichia floridana, Monarda punctata, Liatris scariosa, Lithospermum Gmelini, Tephrosia virginiana,* and *Amorpha canescens.*

The aspect of the mixed consocies varies considerably from one area to another, but a few plants may be mentioned which are usually common and conspicuous. In the vernal aspect *Viola pedata, Pentstemon hirsutus,* and *Lithospermum Gmelini* are in bloom. They are followed during the aestival aspect of July by *Tradescantia reflexa, Chrysopsis villosa, Oenothera rhombipetala,* and *Amorpha canescens.* In the serotinal aspect *Solidago nemoralis, Liatris scariosa,* and a number of other composites appear. The consocies was not under observation during other aspects.

Cultural Changes

The railroads which traverse the sand areas make apparently little effort to keep the right of way free from tall grasses or other plants, and as a result fires occur frequently. Their chief effect seems to be to limit the growth of bunch-grasses to the largest species, and of those only the larger bunches are spared. The deposit of cinders along the track is also an important factor in the vegetation. It tends to increase the intensity of the xerophytic conditions, and hence to limit the plant growth. In this the greater heat absorption of the dark-colored, cindered surface may be controlling for the perennials, while the poorer chance of seed planting may tend to reduce the number of the annuals. The general effect of both fires and cinders is to increase greatly the amount of open space and to restrict the vegetation mainly to a few of the hardier species. There are of course frequent scattered relics of many other species of the association. An association of quite similar appearance, characterized by *Andropogon scoparius* and *Petalostemum purpureum,* appears on some of the gravelly ridges along Lake Michigan, where the surface of the ground is covered with flat rounded pebbles one to two inches (2-5 cm.) in diameter.

North of Oquawka, along the Chicago, Burlington and Quincy railroad there are many huge bunches of *Sorghastrum nutans, Andropogon furcatus,* and *Andropogon scoparius,* separated by interspaces 3-15 feet (1-5 m.) wide. Nearly all these bunches are dead in

the center, showing that they are of great age. But few perennials have persisted, the most notable of which is *Brewcria Pickeringii,* growing in large tangled masses three to five feet (1-2 m.) across.

Along the same railroad near Keithsburg, *Andropogon scoparius* is the dominant species. Burning there has been less frequent, or has not occurred for a longer time, since there are many plants of *Boutcloua hirsuta* and some blue-grass. *Antennaria* frequently forms mats on the ground and there are some patches of *Helianthus occidentalis,* which are so dense that almost all other plant growth is excluded from them. Some other perennials in this habitat are *Ceanothus americanus, Tradescantia reflexa, Solidago nemoralis, Desmodium illinoense,* and *Rudbeckia hirta,* but the most abundant of all is *Euphorbia corollata.* There are comparatively few interstitials.

Along the Chicago and Northwestern railroad southwest of Dixon the surface is thickly covered with cinders but there is little evidence of burning. There is a good growth of *Leptoloma cognatum,* and a few scattered plants of *Panicum Scribnerianum* still persist. *Euphorbia corollata* is abundant, and numerous patches of *Equisetum hyemale,* var. *intermedium* occur. Other secondary plants are *Chrysopsis villosa, Brauneria pallida, Helianthus occidentalis,* and *Monarda punctata.*

Pasturing, if too close, results in the destruction of part of the bunches and a consequent increase in the number of interstitials. If continued too long, the sand may begin to blow, ruining the pasture or possibly even the adjacent fields. The bunch-grasses seem to be poorly adapted to grazing and they are soon displaced by blue-grass. Some of the coarser species are avoided by stock, and persist for a longer time.

On a hillside pasture in the Hanover region *Eragrostis pectinacea* is in most places the only bunch-grass remaining. *Cyperus Schweinitzii* is abundant and blue-grass is appearing in a few patches. The secondary species include a large proportion of annuals, of which *Monarda punctata* is especially abundant. This species with its exceedingly pungent foliage is not eaten by stock and seems to flourish in pastures notwithstanding the tramping. It will be noted that many of the species listed below have a similar protection against grazing animals. The following species were observed.

Grasses:

Setaria glauca
Cenchrus carolinianus
Aristida tuberculosa
Eragrostis pectinacea
Poa pratensis
Cyperus Schweinitzii

Perennials:

Petalostemum purpureum
Petalostemum candidum
Euphorbia corollata
Callirhoe triangulata
Vernonia fasciculata
Liatris cylindracea
Liatris scariosa
Solidago nemoralis
Solidago rigida
Helianthus scaberrimus
Helianthus occidentalis
Artemisia caudata

Interstitials (excluding grasses):

Polygonum tenue
Mollugo verticillata
Draba caroliniana
Arabis lyrata
Polanisia graveolens
Linum sulcatum
Croton glandulosus, var. *septentrionalis*
Euphorbia Geyeri
Oenothera rhombipetala
Monarda punctata
Erigeron ramosus

Arabis lyrata is here sometimes very abundant and covers areas five to fifteen feet (2-5 m.) across to the exclusion of almost all other vegetation. These spots are always covered by gravel sorted out by water action, affording an optimum habitat for the rock-loving plant.

In the Oquawka area *Paspalum setaceum* and blue-grass tend to replace the bunch-grasses. The number of interstitials is increased, and *Monarda punctata, Erigeron ramosus,* and *Ambrosia psilostachya* become especially abundant. A few weedy perennials also remain, such as *Lactuca canadensis* and *Verbena stricta.*

Many of the roads across the sand prairies are little used and the roadsides are occupied by a vegetation very similar to the original bunch-grass. This is particularly true in the Hanover area, which is very sparsely settled. Even there *Poa pratensis* comes in and partially converts the bunch-grass into sod. Thickets of *Ribes gracile* and other berry-bearing shrubs come up along the fence-rows, and their shade is a favorite habitat for *Artemisia ludoviciana.* Various interstitials, especially *Cassia Chamaechrista, Digitaria filiformis, Mollugo verticillata,* and *Cenchrus carolinianus* grow even in the road-bed between the wheel-tracks.

The same general conditions obtain in the Havana and Oquawka areas, but with more travel because of the denser population the original bunch-grass is destroyed or obscured by the numerous weeds that follow civilization. These include two groups, the first composed of species normal to natural associations but flourishing also along the roadsides, and the second of true weeds, mostly natives of the Old World and not found on natural sand associations in the vicinity.

In the first group are *Verbena stricta, Strophostyles helvola, Monarda punctata, Froelichia floridana, Oenothera rhombipetala,* and *Lepidium virginicum.* The second is represented by *Digitaria filiformis, Trifolium pratense, Trifolium repens, Poa pratensis, Verbascum Thapsus, Hordeum pusillum, Anthemis Cotula, Erigeron canadensis, Polygonum erectum, Polygonum aviculare, Achillea Millefolium, Plantago Rugelii,* and *Chenopodium album.*

In the Oquawka area *Populus alba, Gleditsia triacanthos,* and *Robinia Pseudo-Acacia* are frequently planted along the roadsides, and shelter a number of more mesophytic species, such as *Solanum nigrum* and *Phytolacca decandra.*

In cultivated fields the weeds are composed mainly of introduced species and of those natives of the original bunch-grass which are readily propagated by seeds, thus including most of the interstitials and but few of the perennials. In the Hanover area the most abundant are *Lepidium virginicum* and *Rumex Acetosella.* Under certain conditions which could not be determined *Euphorbia corollata* and *Pentstemon hirsutus* come up in great abundance in almost pure association. A square meter taken at random contained 605 plants of the former species, and *Pentstemon* grows almost as densely. Other abundant weeds are *Monarda punctata, Hedeoma hispida, Silene antirrhina, Specularia perfoliata,* and *Diodia teres.* In the Havana area, where the prickly-pear, *Opuntia Rafinesquii,* is common, it frequently becomes a bad weed in corn fields. Cultivation does not kill it, but merely serves to break the plant up into joints and scatter it over a wider area. In the Oquawka area many fields are cultivated some years and abandoned others, and they always contain a heavy growth of weeds. One such field was almost carpeted with *Cenchrus carolinianus,* above which arose the yellow-flowered stalks of *Oenothera rhombipetala* in such numbers that from a distance the whole field looked yellow. The other weeds with them were *Mollugo verticillata, Strophostyles helvola, Polanisia graveolens, Ipomoea hederacea, Croton glandulosus,* var. *septentrionalis, Xanthium commune, Erigeron canadensis, Ambrosia artemisiaefolia, Solanum carolinense, Lepidium virginicum, Cyperus Schweinitzii, Asclepias amplexicaulis,* and *Ambrosia psilostachya.* This field had been in corn during the previous year.

SUCCESSIONS FROM THE BUNCH-GRASS ASSOCIATION

The bunch-grass association just described belongs typically to the Prairie Province. Of the various associations composing the

vegetation of that province and represented on the sand areas of Illinois, this is ecologically the best fitted to meet the environmental conditions under which it lives. Such associations have been called by Cowles *climax associations* (*1899:* 374, *1901:* 80, 81), a term which is both logical and expressive and which has been generally adopted by American ecologists. Some associations, however, which are relatively stable and consequently more nearly permanent, may under certain conditions give way to others, and to this type may be given the name temporary climax, introduced by Cowles (*1901:* 88) to cover a somewhat different case, but applicable here as well.

Within every vegetation province there is one climax association, which tends to displace every other association with which it comes in contact. For the Prairie Province this seems to be the prairie-grass association (Pound and Clements, *1898:* 389), which is very poorly represented in the areas under discussion. In the Havana area it tends to come in at the bottom of extinct blowouts, which have reached a depth sufficient to expose moist strata of sand (Hart and Gleason, *1907:* 168). In the Hanover area certain tracts of bunch-grass occupying depressions between the dunes are composed of an unusually dense and luxuriant covering of grasses in which *Panicum Scribnerianum* occurs (see description of station 1 of the mixed consocies, p. 66). This species is representative in Nebraska and South Dakota of the prairie-grass association (Pound and Clements, *1898:* 389; *1900:* 348; Harvey, *1908:* 102), and may be considered in our area as a pioneer invader in a prairie-grass succession. The environmental and vegetational differences between the depressions mentioned and the remaining stations of the consocies were not considered sufficient to warrant its separation as an example of the latter association. In other cases where *Panicum Scribnerianum* occurs in the mixed consocies the usual bunch-grasses are so well developed that there is no doubt as to the association concerned.

When associations from two provinces come in contact, local conditions, either climatic or edaphic or both, together with the structure of the associations themselves, decide the supremacy, and one is replaced by the other. In the Illinois sand areas the associations of the Prairie Province are surrounded by those of the Deciduous Forest Province, and the bunch-grass association is under certain conditions succeeded by an oak forest. Certain physical conditions, in this case wind, may also destroy the bunch-grass, and open the way for a series of successions, which generally revert sooner or later to the bunch-grass. The fundamental difference between these two types of succession is apparent. One consists merely of changes within the

Prairie Province; the other is between two provinces, leads to the permanent replacement of the prairie vegetation, and consequently affects the area and the boundaries of both the Prairie and the Deciduous Forest Provinces.

Because of the large area occupied, its resistance to succession by associations of the same province, and its ability to reoccupy the space where it has been destroyed by wind action, the bunch-grass association must be regarded as a temporary climax.

The succession caused by wind will be described first. It begins with the development of the *Panicum pseudopubescens* association, and is followed by a number of associations representing the blowout formation.

THE PANICUM PSEUDOPUBESCENS ASSOCIATION

Notwithstanding the resistance offered by the bunch-grasses to removal of sand by the wind, the exposure of from 20 to 50 per cent. of the surface gives considerable opportunity for aeolian action. Large bunches are not destroyed, and probably not seriously injured, by the removal of sand, but the smaller bunches may be killed. With every subtraction from the vegetative covering more sand is exposed and the effect of the wind correspondingly heightened. One species of bunch-grass, *Panicum pseudopubescens,* can not only endure the removal of sand from beneath it, but seems to thrive better under such conditions than when mixed with larger grasses on more stable sand. As the blowing proceeds, an increasingly larger portion of the surface is occupied by it, until finally it becomes dominant, and the bunch-grass association is thereby converted into the *Panicum pseudopubescens* association. Just where the dividing line between the two should be drawn is questionable. It has been arbitrarily decided that the bunch-grass association must have at least half the surface occupied to be considered typical, and it may also be arbitrarily considered that, in the *Panicum pseudopubescens* association, the characteristic species should constitute at least three fourths of the plant covering. When the vegetation does not comply with these conditions it may be regarded as representing transitional stages of this succession or of other successions.

The best development of this association is in the almost original conditions of the Hanover area, but it also occurs in the Oquawka, Dixon, and Havana areas, presenting the same essential characters in each.

Since the development of the association depends primarily upon

wind action, it does not occupy large continuous stretches, but occurs in isolated tracts of generally small size (Pl. III, Fig. 2). It also shows a very definite space relation to the bunch-grass association and to the blowout associations. The former is normally found at the west and northwest, and the latter are at the east and southeast of the *Panicum pseudopubescens* association. This is caused by the prevailingly west and northwest winter winds, together with the successional relations of the associations.

The circular depressed bunches of the dominant species have already been described under the bunch-grass association. They may grow in almost pure association, as far as other bunch-forming grasses are concerned, or may be somewhat mixed with other species. The additional species, however, are never sufficiently abundant to give the general tone to the association, thereby assuming dominant rank. The bunches are separate or confluent in small irregular patches. The intervening areas of bare sand may be two or three feet (6-10 dm.) across, and are invariably conspicuously depressed between the bunches. The elevated position of the bunches gives them an appearance of prominence and individuality not found in the bunch-grass association. Two other bunch-formers, *Carex umbellata* and *Panicum perlongum*, appear quite frequently. The former produces very dense, flat, circular bunches 1-1.5 feet (3-5 dm.) wide, with narrow, stiff, short, closely aggregated leaves. The bunches are conspicuously elevated, sometimes six inches (1.5 dm.), and the larger ones are invariably dead in the center, thus producing a growth-ring. The outer edge of living plants stands at a conspicuous angle, and the dead center is a few inches above the general level of the sand. The regular hemispherical bunches of *Panicum perlongum* have already been described. In this association they grow somewhat more depressed, approaching in structure those of *Panicum pseudopubescens*. *Carex umbellata* scarcely occurs beyond this association, while *Panicum perlongum* is found in the bunch-grass as well. The amount of ground space occupied by these three plants probably never exceeds 75 per cent., and may be less than 50 per cent.

Several other species of bunch-grasses which occur scattered at wide intervals must be regarded as relics of a former bunch-grass association. They vary in species from station to station, and in number of individuals inversely with the age of the association. They are never abundant, but are frequently very conspicuous because of their larger size or erect habit of growth. The species of this character are as follows:

Andropogon scoparius
Leptoloma cognatum
Panicum virgatum
Koeleria cristata
Bouteloua hirsuta
Tridens flavus
Elymus canadensis
Cyperus Schweinitzii
Carex Muhlenbergii

Others of this nature might be expected. Two other grasses, *Paspalum setaceum* and *Sporobolus cryptandrus,* may also occur. They are pioneers, proper to the blowsand and indicative of the probable future succession.

The secondary species, aside from grasses, consist primarily of perennials and interstitials. Correlated with the removal of the sand, the number of species and individuals of the perennials is small, and they are in general to be regarded as relics rather than proper members of the association. The species observed are as follows:

Tradescantia reflexa
Sisyrinchium sp.
Baptisia bracteata
Tephrosia virginiana
Lespedeza capitata
Polygala polygama
Callirhoe triangulata
Viola pedata
Acerates viridiflora
Acerates viridiflora, var. *lanceolata*
Lithospermum Gmelini
Physalis virginiana
Pentstemon hirsutus
Solidago nemoralis
Aster linariifolius
Helianthus scaberrimus

Of these *Lespedeza capitata* is by far the most abundant, with *Helianthus scaberrimus* and *Lithospermum Gmelini* next in importance. Some of the others are represented in single stations, or even by single individuals.

But one instance was observed of the presence of a mat-plant as a relic; *Opuntia Rafinesquii* in the Havana area. This is due to the fact that a bunch-grass association with a good development of mats is far less subject to wind action, and consequently to succession by the *Panicum pseudopubescens* association.

The exclusion of perennials and mats permits a correspondingly larger representation of interstitial species. These come up from seed late in spring and complete their whole cycle of development in the season when the gentler winds and heavier rainfalls keep the sand in a state of relative quiet. The chief species are given in the following list:

Aristida tuberculosa
Festuca octoflora
Cyperus filiculmis
Polygala verticillata
Croton glandulosus, var. *septentrionalis*

Commelina virginica
Rumex Acetosella
Polygonum tenue
Mollugo verticillata
Silene antirrhina
Talinum rugospermum
Lepidium virginicum
Arabis lyrata
Crotonopsis linearis
Oenothera rhombipetala
Monarda punctata
Hedeoma hispida
Linaria canadensis
Erigeron ramosus
Ambrosia psilostachya

Comparing the lists of perennials and interstitials, it will be noted that the latter group is represented by more species, while the number of individuals is vastly greater. The perennials are also infrequent in comparison with the more general distribution of the interstitials. The species in twelve quadrats of approximately four square meters each, in the Hanover area, were listed. The results are shown in the following list, where the numeral indicates the number of quadrats in which the species occurred:

Ambrosia psilostachya (12)
Lepidium virginicum (9)
Lithospermum Gmelini (2)
Oenothera rhombipetala (1)
Croton glandulosus, var. *septentrionalis* (1)
Polygala polygama (1)
Linaria canadensis (10)
Helianthus scaberrimus (4)
Acerates viridiflora, var. *lanceolata* (2)
Solidago nemoralis (1)
Silene antirrhina (1)

The relative frequency of the perennials and interstitials in the list is as 35 to 100. This may be compared with the data given in the description of the bunch-grass association, where in two cases the relative frequencies were as 56 to 100 and as 172 to 100. The interstitial vegetation varies somewhat from place to place, and any species may be locally very abundant. In general, the three leading species in the list are the most important of the group. At any station the species are generally closely similar to those found in the neighboring bunch-grass.

The greatest number of individuals of perennials is found in young associations which have but recently displaced the original bunch-grass, and the number decreases continually with age. The individuals of interstitial species increase in number as the available space becomes larger, but when so much surface is exposed that the blowing of the sand becomes too rapid or continues too long in spring and early summer, the number begins to decrease.

None of the species with conspicuous flowers is abundant enough

to give much color to the association, while the more abundant interstitials have for the most part very small flowers. There is but one season when the association has a well-marked floral aspect. That is during the aestival period when the reddish spikelets of *Panicum pseudopubescens* give a general red tone to the whole. Local displays of color, caused by single plants or groups of *Oenothera rhombipetala, Monarda punctata,* or other species, are conspicuous, but not distributed generally over a whole station.

The duration of the association is usually not great. Since both its beginning and end are caused by wind action, its age depends somewhat upon the rate at which sand is removed. If the destruction of vegetation by the wind is aided by heavy pasturing, its duration is still further shortened, and one station in the Havana area contained at the same time relics of the bunch-grass, *Carex Muhlenbergii* and *Leptoloma cognatum,* and pioneers of the blowsand association, *Paspalum setaceum* and *Sporobolus cryptandrus.* Under other circumstances the blowing may cease, and the association then gradually reverts to the original bunch-grass association.

REVERSION TO THE BUNCH-GRASS ASSOCIATION

The dominant or climax nature of the bunch-grass association has already been mentioned. Whenever those physical conditions which are concerned in producing the *Panicum pseudopubescens* association become inoperative or ineffective, a reversion to the original vegetation begins. This may take place with considerable rapidity, because of the usual proximity of the two associations and the consequent readiness with which migration may take place. Reversion begins not only near the margin of the association, but in the center as well, if that part has ceased blowing. This succession has been observed only in the Hanover area, but undoubtedly occurs at any other place where both associations are present and the environmental conditions are suitable.

The pioneer invader in the Hanover area is *Selaginella rupestris.* Its habit of growth in circular patches allows a comparative estimate of the age of different stages in the succession. Some stations of the *Panicum pseudopubescens* association were observed which were apparently normal except for a few small, regularly circular mats of *Selaginella* near the margin. The number, size, and regularity of the mats all indicate an early stage in the reversion. Later it becomes so abundant that it may form a solid mat on the ground, in which the rings are of large size and overlap each other. Ac-

companying it is an increased development of *Boutcloua hirsuta,* which, as already noted, may almost be regarded as a mat. Until the mats become continuous there is an excessive growth of the usual interstitial plants. *Aristida tuberculosa, Ambrosia psilostachya,* and *Monarda punctata* are especially abundant, and the others of less frequency are *Talinum rugospermum, Specularia perfoliata, Erigeron ramosus,* and *Arabis lyrata.* The latter species frequently grows by the hundred upon the mats of *Selaginella. Opuntia Rafinesquii* also occurs rarely, and the only known Illinois station for *Opuntia fragilis* is in one of these reversional stages and the adjoining bunch-grass association. The perennials probably include both pioneers and relics, but they can not be distinguished in the field. Those observed are *Aster sericeus, Aster linariifolius, Pentstemon hirsutus, Callirhoe triangulata,* and *Lithospermum Gmelini.* Beside the normal bunch-grasses, scattered bunches of other species occur, which may be either relics or pioneers.

As the *Selaginella* mats grow older they become dark and charcoal-like in appearance and are frequently occupied by crusts of *Cladonia.* At a later stage small mats of *Antennaria* come in.

The order of entrance of the bunch-grasses was not observed, but depends largely upon the nature of the neighboring areas of the bunch-grass association. At the border of some of these reversional stages, portions of extremely large mats of *Selaginella* were found in the bunch-grass, indicating the invasion of the grasses from the margin toward the center. The dense mats of *Selaginella* probably serve to check their rapid development.

The Blowout Formation

Of all the features of the action of the wind upon sand, the saucer-shaped or bowl-shaped excavations known as blowouts are the most peculiar (Pl. VII, Fig. 2; Pl. VIII, Fig. 1). Blowouts probably occur in every large unforested sand region. They reach a large size and a considerable depth, and are frequently a prominent feature of the landscape. The physical conditions and the movement of the sand within them have apparently not been fully described, and the vegetation of American blowouts is still very imperfectly known.

Cowles (*1899:* 195-197) mentioned the blowouts or "wind-sweeps" of the south shore of Lake Michigan, but did not describe the vegetation in detail. As usual, they stand in a direction parallel to the wind, and may reach down almost to the water-level. One of them, at Dune Park, Indiana, has steep sides from 30 to 60 feet

(10-20 m.) high, making it much deeper than any in the inland dunes of Illinois. Developing in the midst of moving sand, they may have a different structure and different plant associations from those of the inland regions.

Rydberg (*1895:* 135) described blowouts in the sand-hill region of Nebraska which were 100 yards (100 m.) in diameter and from 50 to 60 feet (15-20 m.) deep. He mentioned how sand slides down from the sides into the basin, but did not describe similar behavior of the vegetation. Certain grasses, as *Calamovilfa longifolia, Redfieldia flexuosa, Eragrostis trichodes,* and *Muhlenbergia tenuis,* colonize in the basin and take part in the stabilization of the blowout. Of these four grasses, *Calamovilfa* and *Eragrostis* live also in the Illinois sand region, but not in blowouts. Rydberg's work was mainly taxonomic in its aims, and the ecological notes which he gives are merely incidental.

Pound and Clements (*1900:* 365-368) later studied the same region from an ecological standpoint, and have given the best description of blowouts and their vegetation. *Redfieldia flexuosa* and *Muhlenbergia pungens* are "habitually and almost exclusively blowout inhabitants." These two grasses are pioneers in binding the sand and creating conditions suitable for other plants. Stabilization apparently begins at the bottom, and ultimately the whole blowout is reoccupied by the bunch-grass vegetation. The description does not give an idea of the structure or vegetation of the other parts of the blowout, which are probably the same in Nebraska as in Illinois. In an earlier paper (*1898:* 392) Pound and Clements described the Nebraska blowouts in a short paragraph, and indicated that the life of a blowout from formation to stabilization may be about ten years. In both papers the "sand-draw" formation is also described (*1898:* 392; *1900:* 368-370). In neither case does the description give a clear idea of the vegetation or the environmental conditions, but it seems probable that the vegetation is somewhat similar to the blowsand association of this paper. No similar habitat occurs in Illinois.

Jennings (*1908:* 324-326) has described blowouts on Cedar Point, near the western end of Lake Erie, which extend down to a former surface level, or fossil beach. On them there is developed sometimes a heath vegetation of *Arctostaphylos Uva-ursi* and *Juniperus,* and sometimes an association characterized by *Artemisia caudata* and *Panicum virgatum.* The complex nature of the blowouts was recognized but the successions which led to their stabilization were not worked out. In a later paper on the vegetation of Presque Isle (*1909:* 313-318) Jennings regards his *Artemisia-Pani-*

cum association as equivalent in habitat to the Illinois blowouts. There are some species in common, but in the opinion of the present writer there is not sufficient resemblance in habitat or flora between the two to justify their classification in the same ecological group.

The only ecological discussion of the inland region of Illinois is by Gleason (Hart and Gleason, *1907:* 162-167, 169-171). The origin, growth, and stabilization of the blowouts of the Havana area were discussed and the typical plants were listed. The different physiographic parts of the blowouts, and their four plant associations and the various successions between them were not recognized.

In the normal development of a blowout, it probably always follows the *Panicum pseudopubescens* association, and consequently appears at the eastern side or in the center of that association. When its development begins in the bunch-grass association, without the intervention of an intermediate society, it is probable that its inception is due to some extraordinary local cause. The stamping of grazing cattle has been suggested as a possible cause, and in one case a blowout started from a hole excavated in removing sand for building purposes.

If a single blowout can increase in size without coming in contact with any others, it shows certain definite physiographic features which appear to be constant. More often, however, several blowouts originate near each other, and, becoming confluent with growth, they form a complex waste of sand (Pl. IV, Fig. 2) which baffles physiographic analysis and sometimes causes the greatest difficulty in classifying the meager vegetation. A complete typical blowout (Pl. IV, Fig. 1) contains four parts, extending from west to east in the direction of the prevailing winds. As a matter of fact the direction of the axis of the blowouts may vary from north-south through west-east to south-north. In the following discussion the direction is always spoken of as west-east, for the sake of brevity. At the western end there is a downward slope from the general level, here termed the windward slope. From it sand is being removed by the wind toward the east, and is also settling down by gravity toward the bottom of the slope. The windward slope generally occupies a more or less crescent-shaped area extending partly around the north and south sides of the blowout. The deepest portion is termed the basin, and from it sand is being rapidly carried away by the wind. Some is also being deposited by wind and gravity from the windward slope, but the resultant is in favor of the general removal of sand. A crescent-shaped sloping area toward the eastern end of the blowout is termed the lee slope. There the rates of erosion and deposition are about

equal; the sand is constantly changing although its level varies but little. Finally an outer crescent, called the deposits (Pl. V), surrounds the lee slope and is somewhat higher than the general level. As its name indicates, it is composed of sand removed from the other three parts and carried up by the wind. A longitudinal section through a typical blowout is shown in Figure 4. The basin shows a constant

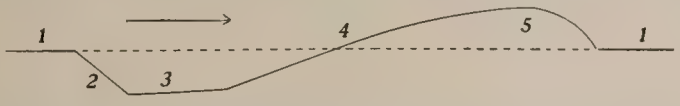

Fig. 4. Diagrammatic longitudinal section through a typical blowout. *1*, original level of sand; *2*, windward slope; *3*, basin; *4*, lee slope; *5*, deposits.

tendency to increase in size or in depth. If this tendency is most pronounced toward the rear, i.e., the west, it is shown by a steep windward slope; if most pronounced toward the front, or east, by gentle windward and steep lee slopes. If all the sand removed is poured out in one direction, the sides become steep and settle by gravity toward the basin. They may be regarded as a continuation of the windward slope and are occupied by the usual vegetation. On the other hand, if the sand is carried out toward the north and south as well as toward the east, the windward slope is small, and the lee slope and deposits extend around three sides of the blowout. Between the two extremes there is every imaginable gradation. A blowout of this simple type is occupied by four plant associations which are usually easily recognizable and which are correlated with the four physiographic divisions.

The maximum observed length of a simple blowout, but without all four parts present, is in this region about 200 yards (200 m.). As their size increases the windward slope may disappear, either by a reduction in its gradient or by stabilization. The continuous crescent of deposits may be broken up into several detached segments, separated by patches of sand corresponding to a lee slope or by promontories covered by bunch-grass and with vertical walls. The slope below these steep-sided mounds usually functions as a windward slope, and is occupied by the characteristic vegetation, even though it is at the eastern end of the blowout. There is also a general progressive movement of the blowout from west to east, so that the stabilized remains of an old windward slope may be found behind the present active one.

Blowouts of this simple type are not common; in fact only one

of large size was observed in which all four parts were present without any apparent modification. Deviations from the normal may usually be referred to three general causes: (1) the blowout is young and not all the parts are developed (Pl. VI, Fig. 1; Pl. VII, Fig. 1); (2) the blowout is old or has ceased its development and part or all of it has become stabilized by the action of plants (Pl. XI, Fig. 2); or (3) two or more blowouts have grown together or smaller secondary blowouts have begun within them, interfering with the regular arrangement of the physiographic features and plant associations (Pl. IV, Fig. 2). Any two, or all three, of these may act together. Observation shows that stabilization may begin in any part of the blowout, whether it is young and small or large and old. When two or more blowouts grow together, the most usual disturbance in their regularity is the combination of the two deposits or the filling of the basin of one by the deposits of the other. The larger the space occupied by the blowout complex, the smaller is the probability of stabilization and the greater the amount of loose sand exposed to the wind. The complex may then occupy several acres of ground and be an actual menace to agriculture in the vicinity (Pl. X, Fig. 1). When in this condition it is locally known as "wild sand." The most notable complex in this respect is the waste known as the Devil's Neck, in the Havana area north of Topeka, where more than forty acres of land is covered by shifting dunes, which have a maximum height of probably 50 feet (15 m.). Blowouts may sometimes develop on the west side of a hill, in which case the windward slope, if any, is composed of one or two lateral slopes on the north and south sides. The basin is relatively high and the bunch-grasses at the windward end are removed by wind alone and not by gravity. Blowouts may also develop on the east side of a hill (Pl. VII, Fig. 1), resulting in a strongly developed windward slope, and in a lee slope and deposit which may be actually lower than the basin.

Attention must be called to the fact that the general effect of the wind is to reduce the elevations and fill up the depressions of the surface. The dunes themselves are initiated and perpetuated by the growth of plants upon their summits. This has been well described by Cowles in his report on the dunes of Lake Michigan (*1899:* 175-190.) Even the migrating or wandering dunes, although carried forward by the wind, leave a trail of sand behind, which would soon exhaust them if continued very far. In a somewhat similar way there is a limit to the size and depth of the blowouts. At the maximum depth the wind is no longer able to lift sand up the lee slope from the basin. If too wide,

the currents of the wind are changed and the bottom of the blowout ceases to be eroded. The basin is thus converted into an extension of the lee slope, where the sand is merely in motion, without an essential change in level. Very little information is available concerning the rate of movement of the sand. That the motion is continuous through the summer is shown by a rough experiment in the Hanover area. A hole about eight inches (2 dm.) deep was dug June 2, 1908, on a flat expanse of sand, with no vegetation except a few plants of *Hudsonia*. On June 13 it was found filled to a depth of two inches (5 cm.). This does not indicate erosion or deposition, but merely the amount of sand which traveled across the area in the given time and was caught in the hole.

In spite of the physiographic diversity, the vegetation, if any, can be referred to four different associations. One of these, which from its position may be called the windward slope association, is primarily relict in its nature, being derived from the bunch-grass or the *Panicum pseudopubescens* association. The basin association consists of a very sparse growth of perennials, analogous to those described by Pound and Clements (*1898:* 392; *1900:* 365) in similar situations in Nebraska. The lee slope is occupied by the blowsand association, limited in duration and consisting almost entirely of annuals. Lastly, the deposit association is composed chiefly of sand-binding perennials, which serve to build up the deposits into dunes. Each of these associations is well correlated with the dynamic conditions of its environment; so well correlated in fact that the vegetation is one of the chief means of recognizing the nature or rate of movement of the sand. When the different physiographic parts are obscured or obliterated in a complex of blowsand, the vegetation is still correlated with the dynamic conditions, and the nature of the movement of sand may be compared with accuracy to the appropriate portion of a normal blowout where the same vegetation is developed. Care must of course be exercised to avoid confusing relics with the typical plants of the station.

The specific composition of each of these associations varies greatly from area to area and from blowout to blowout. The variation is frequently perplexing, and becomes especially so when the number of species is small and the individual plants few or scattered. Relics of a preceding vegetation are also frequently found and add considerably to the difficulty of distinguishing the associations.

The development of a blowout in the prairie is first evidenced by an exposed area of bare sand surrounded by the *Panicum pseudopubescens* association. The young blowout may in fact be regarded

as a mere expansion of the spaces between the bunches. The sand thus exposed is but slightly concave, indicating that wind erosion has only begun. The small quantity of sand removed is piled up in a scarcely perceptible heap along the lee side of the blowout. There is then at the outset a differentiation of two of the physiographic parts, the basin and the deposits, and each of these is soon occupied by its characteristic association. The windward slope and the lee slope may not appear at first, but may be consequent upon the greater development of the excavation.

THE BASIN ASSOCIATION

The basin has always the most meager vegetation of the blowout, and in the first stages is either absolutely bare or occupied by one or two perennials left as relics from the *Panicum pseudopubescens* association. The annual interstitial plants, so abundant in that association, do not grow here because of the removal of sand, which prevents the proper planting of their seeds, as will be shown later. As the blowout deepens and widens, a few hardy deep-rooted perennials appear in the bottom, and these constitute the basin association proper. Most notable among the few species is *Acerates viridiflora* and more especially its varieties *lanceolata* (Pl. VI, Fig. 2) and *linearis*. The varieties reach here their largest size and best development. The roots go down to a very great depth; the stems are one to five in number and lie prostrate on the sand. *Acerates viridiflora,* var. *lanceolata* blooms and produces fruit in this precarious situation; *A. viridiflora,* var. *linearis* has not been seen in fruit or flower, is always smaller in size, and may possibly be a juvenile form of the other variety. These two varieties are more widely distributed and more frequent in the basins than in any other habitat. Many blowouts are entirely bare in the basin except for a single individual of the variety *lanceolata*. The plants are never numerous, but are conspicuous because of the absence of other species. They are known to occur in the Hanover, Oquawka, and Havana areas, and doubtless occur in other regions where blowouts are developed. They also grow in the bunch-grass and *Panicum pseudopubescens* associations, but are never common. It may be that in some blowouts they are merely relics, but their number and frequency in that situation are incompatible with their distribution outside. Again, they have not been seen on the windward slope, where relics might be expected. Also, the only plant in a small secondary blowout, newly excavated on the deposits of an older one, was a single plant, exactly

in the middle, of the variety *lanceolata*. Considering all lines of evidence, it seems conclusive that these two varieties find their optimum habitat in the basins, colonize in the blowouts after the basin is formed, and occupy a place similar to that of the grass *Redfieldia* in the blowouts of Nebraska. The other species represented in the blowouts are *Lithospermum Gmelini, Euphorbia corollata,* and *Lespedeza capitata*. Each of these has deep roots, but they can not live in the more active blowouts, which are either bare or with *Acerates* alone. Rarely a few annuals, of species occurring also on the lee slope, are found with *Acerates,* but it seems probable that their occurrence indicates at least a partial or temporary cessation of wind erosion. If this is the case, they should be regarded as a mere extension of the blowsand association, in which the *Acerates* is persisting as a relic. The perennial *Lespedeza capitata* is also good evidence of the same condition, since, as will be shown later, it is one of the most abundant pioneer species in the stabilization of this part of a blowout.

THE WINDWARD SLOPE ASSOCIATION

As the erosion of the blowout proceeds, the windward slope is formed, as already described. From this, sand is being removed by the wind and is also settling down by gravity. There is little chance for seed burial, because the same wind that carries out sand will also blow away the seeds, and as a consequence the annual plants are absent. But the action of gravity, which brings down sand from above, may also bring down plants. The principal vegetation, therefore, is composed of perennials or grasses of the *Panicum pseudopubescens* association which are undermined and gradually slide down the slope into the basin. The most frequent species is *Panicum pseudopubescens* itself, which seems admirably adapted to live in this shifting substratum. Its usual associate, *Carex umbellata,* also has the same property. These two species seem able to live on this slope under almost any condition of angle or rate of erosion. Scattered bunches may be found on the steep slope below vertical walls of sand capped with the same species. The wall is held vertical by the roots of the grass, until finally a portion of it topples over. If the grasses happen to fall right side up they continue their growth and eventually land at the foot of the hill. Many, if not all, of the remaining grasses of the same association appear on the gentler windward slopes, where the erosion takes place more slowly. The grasses observed are *Leptoloma cognatum, Carex Muhlenbergii, Andropogon scoparius, Bouteloua hirsuta,* and *Panicum virgatum. Lespedeza*

capitata is the most abundant perennial. In one blowout the original bunch-grass association was being undermined: *Viola pedata* and whole mats of *Selaginella rupestris* were not only sliding down the slope, but persisting at the bottom. *Viola pedata* holds a small dune at its base until the erosion gets below the level of its roots, when the whole miniature dune slides down with the plant.

At the bottom of the slope the plants are usually undermined completely and their dead remains are blown away. But if the erosion of the basin is slow they may persist. One blowout (Pl. XI, Fig. 2) in the Oquawka area showed a semicircle of established bunches of *Panicum pseudopubescens* and *Leptoloma cognatum* at the base of the slope, and in their shelter numerous annuals were beginning to colonize.

The vegetation of the windward slope is very open, with at least 90 per cent. of the sand exposed. The individual bunches stand at a much greater interval than in the association above the slope, because only a portion of them survive and the gradual settling tends to separate the remainder.

THE BLOWSAND ASSOCIATION

The lee slope of the blowout, unless the rate of movement is unusually rapid, is occupied by a variable group of annual plants, most of which live also as interstitials in the bunch-grass and *Panicum pseudopubescens* associations. As has been mentioned, the lee slope is an area characterized neither by erosion nor deposition, but by the mere movement of sand. Most of this movement affects only the surface, or extends to but a slight depth. Every autumn and winter countless seeds are blown across the blowouts. There is virtually no chance of their being covered to the requisite depth on the windward slope or in the basin, because there erosion is active. Consequently both of these associations are almost entirely without annuals. But on the lee slope, where the upper layers of sand are almost always drifting, there is a good chance that some of the seeds will be left covered to a depth of an inch (2.5 cm.) or more. This seems to be the minimum depth at which germination takes place, and marks the upper limit of moist sand during the rainy season in June. It is quite probable that this minimum fluctuates with the amount of rainfall, and may be much deeper in drier years (cf. Britton, *1903:* 577).

In late spring and early summer the seedlings appear, and the frequent presence of thousands of dead stems of *Aristida tuberculosa*

indicates that the level, in some places at least, has changed but little since the preceding autumn. Elsewhere seedlings appear on ground without dead stems, indicating that conditions were probably unfavorable for seed planting during the previous year. It may be assumed also that certain tracts covered with plants during one year may be bare the next, because of some slight change in the velocity or direction of the sand movement. So the position and extent of the blowsand association vary from year to year, now extending lower and possibly surrounding some relics of the basin association, now retreating toward the summit of the slope, but always appearing where the movement of the sand tends to bury the seeds to a small, but sufficient depth.

The species of the association vary in their ability to extend out upon the sand. *Aristida tuberculosa* is always the pioneer, and the margin of the association frequently consists of that species alone. This is probably due to the awned grains, which may be able to bury themselves to some slight depth. The grains of *Stipa spartea,* with much longer and stiffer bent awns, are known to bury themselves to a depth of about two inches (5 cm.). Places most densely covered with *Aristida* usually have several other species as well, and their contour generally shows that upon them small deposits, generally less than an inch (2.5 cm.) deep, have taken place. Other conditions being eliminated, small seeds are more apt to be buried than large ones, and it is at once noticeable that the individuals of species with small seeds are vastly more numerous than those with larger ones, as *Cassia Chamaechrista.*

The necessity of seed burial is strikingly illustrated by seedlings coming up in rows over wagon tracks. This has already been mentioned for *Cassia Chamaechrista* (Hart and Gleason, *1907:* 165) and, in a short note (Amer. Botanist *7:* 91), for *Diodia teres.* A blowout in the Hanover area illustrates the effect especially well (Pl. VIII, Fig. 2). At the very edge of the lee slope, where erosion has probably exceeded deposition, there are several curving rows of *Diodia teres,* marking the tracks of a wagon which had been driven in a curve across the sand. To be effective this artificial planting must be deep enough to prevent the seeds from being uncovered by any subsequent erosion.

The species comprising the association, arranged approximately in the order of their abundance, are as follows:

Aristida tuberculosa
Paspalum setaceum
Diodia teres
Commelina virginica
Cenchrus carolinianus
Ambrosia psilostachya

Cassia Chamaechrista
Sporobolus cryptandrus
Oenothera rhombipetala
Croton glandulosus,
var. *septentrionalis*
Euphorbia Geyeri
Froelichia floridana
Tephrosia virginiana
Cyperus filiculmis
Cycloloma atriplicifolium
Festuca octoflora
Polanisia graveolens
Helianthus lenticularis
Hedeoma hispida
Euphorbia corollata
Mollugo verticillata
Polygonella articulata
Crotonopsis linearis
Linaria canadensis
Cristatella Jamesii
Monarda punctata
Lepidium virginicum
Lespedeza capitata
Strophostyles helvola
Apocynum cannabinum,
var. *hypericifolium*
Scutellaria parvula

The majority of these 31 species are annuals, and appear also as interstitials in the bunch-grass and *Panicum pseudopubescens* associations. One, *Apocynum cannabinum,* var. *hypericifolium,* is a perennial, but behaves as an interstitial in this habitat. Its occurrence was noted but once. The three true perennials, *Euphorbia corollata, Lespedeza capitata,* and *Tephrosia virginiana,* and the one bunch-grass, *Sporobolus cryptandrus,* are all more numerous on the deposits or in other associations, and their presence here is either casual or else indicative of a succession by the deposit association.

But one species, *Aristida tuberculosa,* is equally common over the four areas studied. Scarcely a blowout was observed which did not have hundreds of plants of this slender grass growing on the lee slope. The other leading species are more local in their distribution. *Diodia teres* is particularly characteristic of the Hanover area, is also common, but local, in the Havana area, but was not observed in the other two areas. The Oquawka blowouts are marked especially by *Commelina virginica* and *Paspalum setaceum,* while *Cenchrus carolinianus* is most abundant in the Havana area.

Excluding the Dixon area, in which there is comparatively little blowing sand, from 17 to 22 of the 31 species occur in each area. Within each area the flora varies from one blowout to another, and a comparatively small portion of the flora appears in any one. Notwithstanding this great local variation between stations, there is no evidence that more than one association exists. The different combinations of species represent merely alternations in the structure of the association, which are not definite enough to demand classification or description as separate consocies.

An interesting phenomenon caused by the dead stems of *Aristida tuberculosa* is frequently observed in the spring and early summer. The dead culms of the preceding year lie flat on the sand but remain firmly attached at the base. When blown by the wind they swing around in arcs of a circle and the tips scratch concentric curves in the sand. The maximum diameter of these wind circles is about three feet (8 dm.), and the average arc about 60 degrees, although some complete circles were observed.

THE DEPOSIT ASSOCIATION

The chief difference in physical environment between the lee slope and the deposits is the nature of the movement of the sand. On the deposits sand is being added by the wind more rapidly than it is being moved away, so that there is a gradual increase in height. This soon leads to the development of a ridge, its size depending naturally on the size of the basin which furnishes the sand. When sand is piled up by wind alone, unimpeded by obstacles of any sort, it is distributed rather uniformly over a considerable area. The resulting dune has a very gentle windward slope and a slightly steeper face. According to Cowles these slopes are about 5 degrees and 30 degrees respectively (*1899:* 191). Sand can not accumulate to a great depth because of the full exposure to the wind, and the dune is sometimes so flat that it almost escapes attention. The blowouts in the Oquawka area are particularly notable for their broad, flat deposits, which are usually not more than three or four feet (1 m.) above the general level. Their vegetation differs but little from that of the lee slopes of the blowout.

For building up the steeper dunes, so characteristic of the blowouts in the Hanover area, the wind alone is not sufficient. There must be an obstacle of some sort which will cause the wind to drop much of its load of sand at one spot, and which will also prevent its removal by other winds from the same or different directions. This obstacle must grow up with the dune, otherwise it would eventually be covered and its efficiency destroyed, and it must last through the winter, when the wind is strongest. All of these conditions are met only by plants, a few species of which become, because of their growth habits, the chief dune-builders of the region. Cowles has shown very clearly the necessary characteristics for a good dune-forming plant (*1899:* 175-190). They are (1) a perennial life, (2) the ability to spread radially by rootstocks (with certain exceptions), (3) the power of growing out into the light when buried

by sand, (4) the ability to adapt the root to a stem environment or the stem to a root environment, depending upon burial by sand or exposure by its removal, and (5) a good set of xerophytic structures, which enable the plant to withstand the extreme conditions of its environment. To these might be added a sixth requisite, the persistence of the subaerial parts during the winter. In every dune region there are some plants which fulfil all or some of these requirements, and which are responsible for the construction of the local dunes. In Illinois the principal ones are *Rhus canadensis,* var. *illinoensis, Ceanothus ovatus, Panicum virgatum,* and *Tephrosia virginiana.* These are discussed in the order of their effectiveness.

Tephrosia virginiana (Pl. IX, Fig. 1) is a perennial herb with very long, slender, tough roots. Several stems, each 1-1.5 feet (3-4 dm.) high, arise from a common base and are densely covered by leaves. These serve to catch the sand and hold it during the summer, but they die in autumn and the dead stems are soon removed by the winter storms. The sand is then held by the subterranean root system only. *Tephrosia* endures covering by sand if it is not to too great a depth, at least not exceeding half the height of the stems. It does not possess the power of unlimited growth during the season, and is consequently not able to keep above the sand indefinitely. Neither is it a very efficient sand-binder, and it dies if the crown and a few inches of the roots are exposed (Pl. IX, Fig. 2). Such cases are seldom seen, because the dead remains are soon blown away. From both of these reasons it is clear that *Tephrosia* is not a very efficient dune-former, and this is fully substantiated by field observation. *Tephrosia* dunes are low and gently sloping (Pl. VII, Fig. 2), and are found mainly on blowouts where the rate of sand movement is apparently very slow. This, of course, does not prohibit the plant from growing on larger dunes in company with other species. It is always associated with *Aristida tuberculosa.*

Panicum virgatum is by all odds the most abundant dune-former in the Hanover area (Pl. IV, Fig. 2). While it does occur in the bunch-grass association, it is much more abundant on the deposits, and in the area mentioned even the smallest and youngest blowouts are sometimes marked by a conspicuous growth of the plant on their newly formed deposits (Pl. VI, Fig. 1; Pl. VII, Fig. 1). In the Havana and Oquawka areas it is infrequent, and the dunes are usually formed and held by some other species. Like *Tephrosia,* it has a large number of very deep tough roots which help bind the sand, and it also spreads slowly by rhizomes. The subaerial parts have the typical bunch-grass structure, and the dense basal leaves act

efficiently in catching and holding the sand during the summer. After the death of the leaves and culms in the autumn, they still persist, and continue to build up the dune during the winter. These dead bunches are frequently partly covered, but the new growth of the succeeding spring comes up through the sand, and bunches entirely destroyed by burial were not observed. The species is accordingly a very efficient dune-former, and builds up steep dunes from two to ten feet (1-3 m.) high. The infrequency of the plant in situations from which sand is being removed gives no opportunity to estimate its ability to withstand uncovering. In a few cases relic bunches have been seen on windward slopes, but it is probably not well adapted to undermining.

Rhus canadensis, var. *illinoensis,* while not so abundant as *Panicum virgatum,* is the most effective dune-former in our inland dunes. It is characteristically a species of the open bunch-grass association (Pl. VII, Fig. 1), where it produces dense rounded thickets up to a yard (1 m.) in height and frequently several yards across. These thickets are so dense that at a little distance they appear as a solid mass of foliage. Within there is a tangle of stems, with the leaves mostly near the ends. The roots are long, and penetrate very deeply into the soil. Fruit is produced abundantly and is probably scattered widely by birds, yet comparatively few young plants are seen and none at all have been seen on the deposits of the blowouts. Its presence there is probably in most cases due to persistence from the bunch-grass which preceded the blowout. It may occur, therefore, at either side or at the deposit end. The number of blowouts where it so occurs depends upon its frequency in the adjoining bunch-grass. It has not been observed in the *Panicum pseudopubescens* association or on the windward slopes of the blowouts. The efficiency of the plant in building up dunes is due to its habit of growth in dense compact masses and to its ability to withstand burial by sand. The blowing sand is caught and held by the dense thickets, and accumulates in a rounded heap conforming to the shape of the thicket. The accumulation continues until the sand reaches within six or eight inches (1-2 dm.) of the top of the thicket. There is little difference in the outward appearance of such a partly buried thicket, although the leafy twigs protrude but a few inches above the sand. When the leaves fall in autumn they also tend to accumulate between the twigs and thus protect the sand from erosion during the winter. The sumach is not injured by this partial burial, but in each successive season grows farther upward and outward, maintaining its position above the sand and causing the rapid growth of the dune

As the thicket becomes larger, portions of it may die away and leave unprotected areas between smaller thickets. These bare spots are usually one or two feet (3-6 dm.) below the general level of the dune, indicating the erosion of the sand after the death of the sumach. The steepest and highest dunes are invariably held by the sumach. The highest ridges along the Mississippi river, which will be described later, are usually crowned at their very summits by scattered patches of sumach, whose large size and irregular outlines bear witness to their great age.

Ceanothus ovatus behaves in a way similar to *Rhus,* but is much rarer. It is more susceptible to injury by burial and does not possess so great a capacity for unlimited growth above the accumulating sand. *Ceanothus* dunes have been observed only along the Mississippi river in the Hanover area.

Besides these plants which are of chief importance, a few other perennials or grasses may locally aid in building up dunes. They are, however, generally temporary in their nature and persist only during the summer when the plants are growing. Their size depends upon the habit of the plant, but seldom exceeds a foot in height. The larger dunes of this type are formed by *Euphorbia corollata, Stipa spartea, Sporobolus cryptandrus,* and *Paspalum setaceum.* Even annuals, if growing in close patches, may accumulate an inch or so of sand around them. *Euphorbia Geyeri* and *Mollugo verticillata,* the two common prostrate species of the deposits, do not accumulate sand, but their flat close mats prevent erosion if it is not too rapid. They are sometimes seen growing on plateaus a half-inch (1-2 cm.) in height, and corresponding with the shape and size of the plant. *Mollugo* reaches its largest size on the deposits, forming mats sometimes two feet (6 dm.) across.

Two general types of deposits may be distinguished; those with and those without effective sand-binders. Examples of the latter class are broad and low with gentle slopes, and scarcely differ in vegetation from the neighboring blowsand association, of which they may be considered an extension. When the blowout is young and small the annual increment of sand is but a few inches thick and affords optimum conditions for the burial of seeds of the annuals. The young deposits are accordingly covered with a dense growth of these plants, and under such circumstances may be regarded, as far as the vegetation is concerned, as extensions of the lee slope. If efficient sand-binders do not appear on the deposits with the subsequent growth of the blowout, the vegetation remains essentially the same, except for the addition of various species of perennials. The most

abundant grasses, *Cenchrus carolinianus* and *Paspalum setaceum,* are not injured by burial to a slight depth, but are easily undermined. They find their optimum conditions on deposits of this type, where their fruits are easily buried and where the annual deposit of sand is not sufficient to injure them. If the deposition becomes too rapid and the fruits are buried too deeply, the sand remains entirely bare (Pl. V). The best observed example of this condition is a large dune just south of Keithsburg, in the Oquawka area (Pl. X, Fig. 1). The top of the dune is here entirely bare. At its base along the lee side is a zone of sparse vegetation consisting of *Helianthus lenticularis, Euphorbia corollata, Cenchrus carolinianus, Cycloloma atriplicifolium* and *Lespedeza capitata.* A line of dead plants of *Helianthus* shows that the annual forward movement of sand is about 15 feet (5 m.).

None of the four most efficient sand-binders is abundant in the Oquawka area, either in the bunch-grass or on the deposits. The blowouts there are mainly broad and shallow, with similarly broad flattened deposits, spreading out fanwise over a large area. They are occupied especially by *Cenchrus carolinianus* and *Paspalum setaceum,* with most of the species of the blowsand association. With these are a few additional species, such as *Sporobolus cryptandrus, Leptoloma cognatum, Panicum pseudopubescens, Boutcloua hirsuta,* and *Lespedeza capitata.* These five species do not occur on the regular lee slopes, and represent the deposit association in the narrower sense. The Havana dunes resemble those of the Oquawka area and have in general the same vegetation. *Paspalum setaceum, Cenchrus carolinianus,* and *Sporobolus cryptandrus* are the usual species. Deposits of this type occur rarely in the Hanover area also, and then generally in connection with secondary blowouts which have developed on parts of other larger ones. They are especially characterized by the abundance of *Diodia teres.*

The second type of deposit is marked by the presence of effective sand-binders, and is best developed in the Hanover area. Usually *Panicum virgatum* or *Tephrosia virginiana* appears immediately on the youngest deposits and begins at once the building of the dune. They may appear at a later stage, but in either case the result is the same. Dunes may be held by *Panicum* or *Tephrosia* or by both together. They seldom appear in association with *Rhus,* probably because the rate of increment of a *Rhus* dune is too rapid to permit their growth there. Associated with them are a large number of annuals, such as occur also on the lee slopes. They are most numerous on the *Tephrosia* dunes, which are of relatively slow growth, and least numerous on the rapidly growing *Rhus* dunes. If the

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dune is held by *Panicum virgatum*, it is usually distributed uniformly around the deposits, and the dune is approximately uniform in height. The bunches of grass are seldom more than a yard or two apart and most of the intervening space is occupied by annuals. *Stipa spartea, Andropogon furcatus,* and *Carex Muhlenbergii* are sometimes associated with *Panicum* and are probably relics. *Carex umbellata, Panicum pseudopubescens, Koeleria cristata,* and *Viola pedata* are less frequent and are undoubtedly relics. Because of the relic nature of the sumach on the deposits, a dune seldom has more than one thicket of it. At that place the dune rises much above the general level and has steep slopes occupied by relatively few other plants. At a little distance from the sumach thicket the bunches of *Panicum* and *Tephrosia* appear. On such blowouts the deposits frequently become irregular or one-sided, or the direction of deposition may be changed, because of the greater efficiency of the sumach as a sand-binder.

SUCCESSIONS BETWEEN THE ASSOCIATIONS OF THE BLOWOUT FORMATION

As the *Panicum pseudopubescens* association becomes more open and more bare sand is exposed in the formation of a young blowout, it is difficult to decide just where the dividing line between the two types of associations should be drawn. For convenience it may be considered that a blowout begins with the first appearance of areas of deposition and erosion, that is, with the differentiation of basin and deposit. These two physiographic structures are very soon occupied by their usual vegetation. The windward slope and its attendant plant association appear as soon as the increasing size and depth of the basin begin to disturb the bunches of *Panicum pseudopubescens* in the rear. Between the basin and the deposits there must be at least a small space where the movement of sand is about neutral, and this represents an incipient lee slope. The typical vegetation, however, does not appear during the earliest stages of the blowout. The four associations, therefore, appear in the following order: (1) the basin and deposit associations, (2) the windward slope association, (3) the blowsand association.

These four physiographic parts constitute a definite series as to structure and development, but their vegetation does not fall into a regular successional series. That is, an area now occupied by the windward slope association may not, and probably will not, be occupied in turn by the basin, the blowsand, and the deposit associations. The successions are, instead, very complicated and irregular.

The successional relation between the *Panicum pseudopubescens* and the windward slope associations is self-evident, since there is an actual transfer of individuals from the former to the latter. The basin is developed directly within the *Panicum pseudopubescens* association by a mere change in the nature of the sand movement, and also represents a direct succession. Because of the environmental conditions there are seldom any relics which survive. The succession represents a case where the preceding vegetation is entirely destroyed before the next stage appears. The deposit association also succeeds the *Panicum pseudopubescens* association directly and relics frequently occur. On the lee slope the movement of the sand is similar to that going on in the intervals between the bunch-grasses, so that the blowsand may be regarded as another direct succession. All four associations of a typical blowout, therefore, may and do arise simultaneously and independently.

The general appearance of a typical young blowout is shown in Plate VI, Fig. 1. The total width of the blowout from west (left) to east (right) is about 20 feet (6 m.). At the left is the edge of the *Panicum pseudopubescens* association, with many relic bunches of *Andropogon scoparius* and in the extreme left foreground a bunch of *Carex Muhlenbergii.* From this will develop the windward slope association. Along the right is a conspicuous zone of *Panicum virgatum,* marking the deposit association, with relic bunches of *Panicum pseudopubescens* and *Carex umbellata.* The central basin is still bare and the lee slope is scarcely differentiated. A transect across this blowout is given in Table III.

TABLE III.—TRANSECT OF 20 QUADRATS, EACH 5 DM. SQUARE, ACROSS THE BLOWOUT SHOWN IN PL. VI, FIG. 1.

Linaria canadensis	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panicum pseudopubescens	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Andropogon scoparius	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bouteloua hirsuta	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca octoflora	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex Muhlenbergii	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Carex umbellata	-	-	-	-	X	X	-	X	-	-	-	-	-	-	-	X	X	-	-	-	-
Lespedeza capitata	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Croton glandulosus	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Aristida tuberculosa	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Ambrosia psilostachya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Panicum virgatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X		
Equisetum laevigatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X		
Koeleria cristata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-		

The subsequent successions of vegetation depend primarily upon the physiographic changes. As the development of the blowout proceeds, the basin may begin to encroach on the windward slope. This is caused either by an increase in depth or by a general movement to the rear, or by both together. The sliding vegetation of the latter association reaches the bottom of the slope, is undermined and blown away, and its place is taken by plants of the basin. The windward slope thus comes to occupy a place intermediate in time between the basin and the *Panicum pseudopubescens* associations. If the basin is moving backward without an attendant increase in size, the lee slope will also extend backward over the extinct basin, constituting another succession. If the general movement is forward, the conditions are reversed and the basin association succeeds the blowsand association. This forward movement, however, reduces the grade of the windward slope, and eventually stops the settling of the sand. With this change in its environmental condition, stabilization begins, as will be described later, and the windward slope association is succeeded by the bunch-grass. So, while the basin may succeed the windward slope, the reverse does not take place.

Succession may also take place in either direction between the blowsand and the deposit associations. This depends in part on local environmental changes, leading to the increase in size of one association and the corresponding restriction of the other, but principally upon the direction of the general movement of the whole blowout. If forward, the blowsand association succeeds the deposit association; if backward, the reverse is true.

As has been previously mentioned, the basin of a blowout may eventually become so wide or so deep that further erosion by the wind is impossible. Erosion is the one factor of the environment which is chiefly responsible for the development of the basin association, and when that ceases the basin is at once replaced by a different type of vegetation. Some of the basin plants may persist for a time as relics. It seems probable that the first new vegetation is the blowsand association, mainly because of its proximity, its excessive seed production, and its rapid development. When the sand becomes stationary, it is no better suited to the blowsand plants than to a number of others, including bunch-grasses and perennials. These at once begin to colonize in the blowout and the stabilization of the basin is effected.

With the extinction of the basin the source is destroyed from which sand is added to the deposits, and they cease their growth. The surface of the sand, so far as it is not protected by the dune-

forming plants, remains more or less in motion and affords an environment suitable for the development of the blowsand association, which then becomes dominant. This condition is much like that on the broad flat deposits without dune-formers, where the rate of deposition is slow, because of the large surface to be covered, and the vegetation accordingly consists of the blowsand association. On the deposits this association persists longer than in the basin, because the greater exposure of the sand to the wind keeps it longer in motion. Finally the motion stops, and the deposits are also completely stabilized by various outside species, chiefly bunch-grasses. On the steeper slopes, held by *Rhus canadensis,* var. *illinoensis, Panicum virgatum,* or other species constituting the real deposit association, there is less opportunity for the development of the blowsand vegetation, because the perennials persist and retain their dominancy. They are finally joined by additional species, until eventually the surface is covered and the sand completely stabilized.

Summing up the successions within a single blowout (Figure 5), it is seen that there exists a perfect correlation between the vegetation and the physical conditions of the environment. The original *Panicum pseudopubescens* association is succeeded by each of the four blowout associations. Between these four, the successions depend partly upon the direction of movement of the blowout as a whole. The windward slope association may be succeeded by the basin association, but the reverse does not take place. Between the other three, the succession may be in either direction. The blowsand association shows a general tendency eventually to succeed both of the others, and may be regarded as the climax association of the blowout formation. This is directly correlated with the general dynamic effect of the wind, which leads, on the average, neither to erosion nor deposition, but merely to the movement of the sand. This condition is most favorable to the blowsand association, and is the cause of its dominancy It is probable that the blowsand vegetation would also appear on the windward slope after it has become static, but the relic bunch-grasses become at once the controlling feature, among which the blowsand species play a secondary part as interstitials.

When one blowout is filled by the deposits of another, or when secondary blowouts appear on the lee slope or deposits of an older one, there may be deviations from this normal series of successions. In the latter case the young blowout may be wholly or partially surrounded by a blowsand association, and the windward slope association is never developed because of the absence of any relic plants. When two or more blowouts unite to form a complex waste of sand,

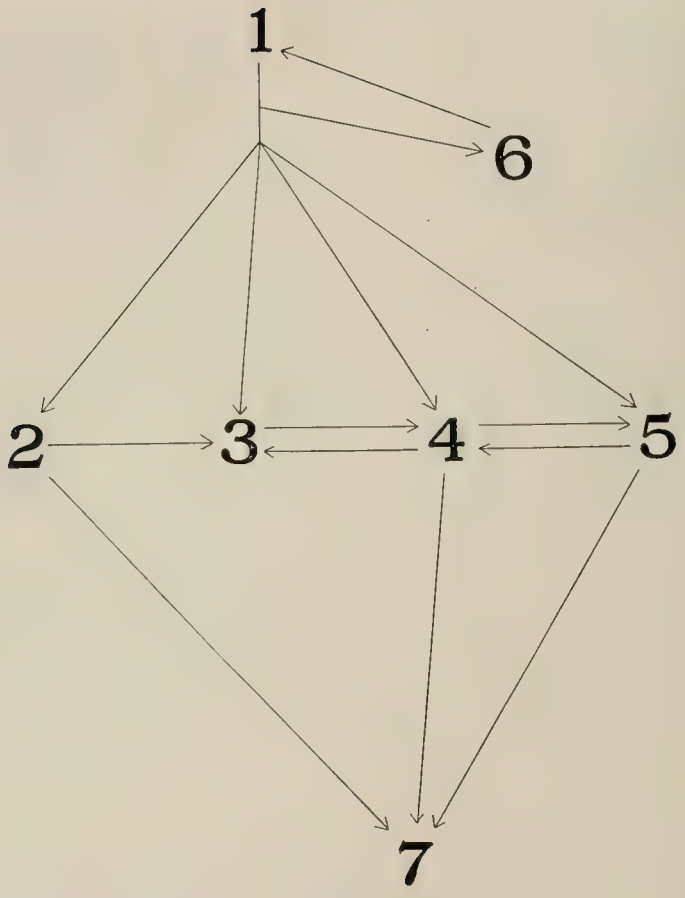

Fig. 5. Normal successional relations between the *Panicum pseudopubescens* (*1*), windward slope (*2*), basin (*3*), blowsand (*4*), deposit (*5*), *Hudsonia* (*6*), and bunch-grass (*7*) associations.

it becomes impossible to decipher the entire past history of the vegetation, but any of the successions given in the diagram between the basin, blowsand, and deposits may occur repeatedly, in any order, and for any length of time, until finally the sand becomes static and stabilization begins. The windward slope association alone is not included in the blowsand complex. It can follow only the *Panicum pseudopubescens* or more rarely the bunch-grass association, and if not succeeded by the basin association reverts to bunch-grass.

STABILIZATION OF THE BLOWOUTS AND THEIR REVERSION TO BUNCH-GRASS

Stabilization of the blowouts may take place in any or all of the four parts. Usually it begins on the windward slope and takes place last on the deposits. The windward slope is already occupied by bunch-grasses, although at a considerable distance apart. When the movement of sand ceases, other species invade the area at once and appear in large numbers between the bunches. *Aristida tuberculosa* and other members of the blowsand association are prominent but do not become dominant. Following them come *Oenothera rhombipetala* and *Lespedeza capitata,* making a thick weedy growth, and later various species of bunch-grass.

In the basin and on the lee slope stabilization begins with the extraordinary development of the blowsand association. It is followed immediately by large bunches of *Sporobolus cryptandrus* and by a rank growth of *Oenothera rhombipetala* and *Lespedeza capitata* (Pl. XI, Fig. 2). *Sporobulus cryptandrus* sometimes lives in actively blowing sand, but only in small depressed bunches (Hart and Gleason, *1907:* pl. XVIII, fig. 2). In partly stabilized blowouts it forms dense bunches one to two feet (3-6 dm.) wide and 1-1.5 ft. (3-5 dm.) high, surmounted by culms two or three feet (6-9 dm.) tall. Beneath the shelter of these three plants a number of interstitial species colonize, many of which are not common in the blowsand association. Some of these are *Hedeoma hispida, Polygonum tenue, Scutellaria parvula, Silene antirrhina,* and *Festuca octoflora.* This weedy growth lasts a comparatively short time. One blowout was observed where only about half as many plants of *Lespedeza* were growing as had grown the previous year, as shown by the dead stems. Since stabilization usually begins near the bottom of the blowouts, some may be found in which *Lespedeza* and *Oenothera* have already left the deepest part and occupy a ring around the sides. This also shows that the bunch-grasses which follow are not plants which slide in from the sides, as was intimated in an earlier paper (Hart and Gleason *1907:* 169). In this tangle the bunch-grasses gradually appear (Pl. X, Fig. 2), and by their growth restrict the interstitials, as was explained in connection with the bunch-grass association. Mats of *Antennaria, Cladonia,* and moss also appear very early. The perennials follow the bunch-grasses. The order of their appearance is not definite, but depends upon the composition of the neighboring bunch-grass association. Stabilization of the basin and windward slopes may take place at the same time, or there may be

a stabilized area behind the active basin, following it as it moves forward.

The flat open deposits without efficient dune-formers are stabilized in nearly the same way. *Paspalum setaceum* first becomes more abundant and is followed by large numbers of *Sporobolus cryptandrus,* with the usual growth of *Lespedeza* and *Oenothera.* Following these the bunch-grasses appear. A tract in the Oquawka area shows the results of twelve years of stabilization in this way. The field was formerly blowing actively, until some locust trees were planted as a windbreak at the west side. In the twelve years that have elapsed most of the blowouts have become extinct and the extensive flat deposits have been almost entirely stabilized. *Oenothera rhombipetala* and *Leptoloma cognatum* constitute the dominant species at the present time. The bunches of the latter are round and compact, but widely separate, and cover only about 30 per cent. of the ground. *Oenothera* is so abundant that when in bloom it shows almost a solid mass of color. But nine accessory species have appeared: *Paspalum setaceum, Ambrosia psilostachya, Bouteloua hirsuta, Croton glandulosus,* var. *septentrionalis, Cyperus Schweinitzii, Lepidium virginicum, Monarda punctata, Verbena stricta,* and *Physalis virginiana.* Proceeding up the lee slope from a partially active blowout toward this newly developed bunch-grass, the grasses appear in the following sequence: *Paspalum, Sporobolus, Leptoloma.* In this case the horizontal arrangement probably indicates the succesion in time as well.

THE HUDSONIA ASSOCIATION

In the Hanover area blowouts are sometimes stabilized by *Hudsonia tomentosa,* which forms a peculiar association of its own. *Hudsonia* grows in dense hemispherical tufts up to 4 dm. in diameter and is always gregarious, occupying 10 to 50 per cent. of the whole surface. It can not endure burying and does not possess the power of growing up with the deposition of sand. Consequently it does not live on deposits. Similarly it can not well resist undermining and does not live in basins or on windward slopes. Neither has it been observed on actively moving lee slopes, nor is it able to hold its own in competition with bunch-grass. Its optimum habitat seems to be open quiet sand, and it is restricted therefore to young blowouts in which the surface is nearly flat and the sand is not actively in motion, or to small portions of more active blowouts where it is able to get a foothold. The plants appear first at the

edge of the bare sand and soon cover the whole area. When a colony is once established it effectually checks any further movement of the sand. Colonies in young blowouts are usually surrounded by *Panicum pseudopubescens,* which soon closes in and reoccupies the space. A few plants of *Hudsonia* may persist for a time, but their life is short. But few other species occur in the association. Those observed are *Cassia Chamaechrista, Euphorbia corollata, Polygonella articulata, Carex umbellata,* and *Andropogon scoparius.* The last two are probably pioneers in the redevelopment of the *Panicum pseudopubescens* or bunch-grass association.

Successions from the Blowout Formation

As the blowouts increase in size and become progressively deeper the movement of the sand becomes less active, and in nearly every case they finally become stabilized and revert to the bunch-grass association. The few cases where the reversion does not take place are of interest, since they illustrate a peculiar series of successions and introduce some associations not found elsewhere in the sand regions under discussion.

The general vegetational and environmental conditions of one type of these successions have been given by Gleason (*1907:* 167-169) from observations on a few blowouts in the Havana area. The principal changes in the ecological conditions are in the direction of protection against wind, resulting in a stable substratum, and a larger supply of water, depending upon the depth of the blowout. These conditions, rather unusual for the sand-areas, permit the development of a more mesophytic vegetation. This is generally simply a more luxuriant growth of bunch-grass composed of the usual species. More rarely entirely different species appear, especially if there are groves or cultivated grounds near.

The Blowout Thicket Association

A simple case, leading to what may be named the blowout thicket association, is shown in a blowout near Oquawka. The blowout is nearly stabilized, with the usual growth of *Lespedeza* and *Oenothera,* but in the very bottom two locust trees (*Robina Pseudo-Acacia*) have become established. Under them are plants of *Oxybaphus nyctagineus, Lactuca canadensis,* and an unknown grass, of a species not occurring in the surrounding bunch-grass. In another blowout several young plants of *Populus deltoides* are growing (Pl. XI, Fig. 2). In a similar deep blowout in the Hanover area is a large tree

of hackberry, *Celtis occidentalis,* probably forty or fifty years old. Under it are shrubs of apple, *Cornus Baileyi,* and *Rosa* sp. They are overhung with vines of *Psedera quinquefolia,* and in their shade are plants of *Polygonatum commutatum.* Many other common sand plants are associated with them. It is probable that all these species were introduced by birds, since they all have fleshy fruits. *Vitis vulpina, Menispermum canadense, Populus deltoides,* and *Acer Negundo* were reported by Gleason (Hart and Gleason, *1907:* 168) for similar conditions in the Havana area.

Although these three blowouts have no species in common, the vegetation probably represents the first stages, changed considerably by proximity to civilization, of a definite series. This series, however, has always been curtailed by refilling the blowouts with sand, since there is no association in the three areas mentioned which can possibly be referred back to this origin.

THE STENOPHYLLUS ASSOCIATION

It has already been mentioned that a thin layer of loamy soil is formed on the surface of the sand in the bunch-grass association. This layer is coherent and quite resistant to wind action. The deposits of a blowout may bury this soil layer to a considerable depth and for an indefinite time, completely destroying the original vegetation. At a subsequent period another blowout may develop on these deposits and finally expose the old soil layer. When this is uncovered the growth of the blowout in depth ceases. Its future growth, if any, is lateral, leaving a flat bottom which is level or gently sloping. Blowouts of this type are generally easily recognized by the bottom being flat instead of the usual concave shape. As soon as the soil layer is uncovered a new type of vegetation appears, characterized particularly by the small sedge *Stenophyllus capillaris,* and constituting the *Stenophyllus* association.

This is well illustrated by several blowouts in the Hanover and Oquawka areas. One in the former (Pl. XI, Fig. 1) is of special interest since it shows the old soil over the western half of the blowout, while the other half is still pure sand, with the usual vegetation. The western half is flat, but slopes up about one foot (3 dm.) in its total width of 25 feet (8 m.), indicating the gently rolling nature of the original surface. The soil layer is covered with one to two inches (2-4 cm.) of fresh sand, blown in from an active blowout toward the west. This portion of the blowout is occupied by numerous small tufts of *Stenophyllus* about an inch (2-4 cm.) wide, a

square foot containing on an average from 75 to 100 plants. Associated with it are numerous plants of the blowsand association: *Diodia teres, Aristida tuberculosa, Croton glandulosus,* var. *septentrionalis, Linaria canadensis, Mollugo verticillata, Cyperus Schweinitzii,* and *Euphorbia corollata.* The presence of these accessory species is probably correlated with the thin deposit of fresh sand, since they are not found on the soil layer proper. A blowout of the same type in the Oquawka area (Pl. XI, Fig. 2) is about 80 by 100 feet (25 by 30 m.) in size, but less than three feet (1 m.) deep. Most of the broad flat basin is covered with a black crusted soil layer and occupied by large numbers of *Stenophyllus* and a few plants of *Gnaphalium polycephalum* and *Lactuca scariola,* var. *integrata.* There are also two circular patches of an unknown moss, probably only two or three years old. Parts of this basin are still covered with a thin layer of sand, on which the vegetation is the usual blowsand association, characterized especially by *Cenchrus carolinianus, Froelichia floridana,* and *Paspalum setaceum.* Stabilization has already begun with *Lespedeza capitata* and *Oenothera rhombipetala,* and at one end are a few plants of *Populus deltoides.*

It seems probable that this association is finally succeeded by a prairie vegetation, although no evidence of this was seen during the present investigation. According to Gleason (Hart and Gleason, *1907:* 168) it may be followed in the Havana area by *Cladonia* and *Antennaria,* and later is converted into "prairie, scarcely distinguishable, in vegetation at least, from the typical prairies of central Illinois."

The Swamp Formation

the salix and solidago associations

Blowouts may become so deep that they reach and uncover moist layers of sand, probably not far above the water-table. In these, new plant associations soon appear, which may be even hydrophytic in nature. The few cases observed have not made it possible to determine the order in which the vegetation develops, and the discussion must be limited mainly to the simple description of conditions as they are. Cowles has mentioned a similar succession at the head of Lake Michigan (*1899:* 308).

The deepest of the excavations, measured by the vegetation rather than by actual dimensions, is in the "Devil's Neck" north of Topeka, in the Havana area. The center of the depression is a sandy loam and probably represents the subsoil, the Miami loam of

the Soil Survey, on which the sand is superposed. It is occupied by a sparse vegetation of *Ludvigia palustris* and *Eleocharis obtusa.* Surrounding it is a zone of *Salix longifolia,* now about three feet (1 m.) high, and *Juncus acuminatus.* Outside of this are the usual plants of stabilized blowouts, particularly *Oenothera rhombipetala* and *Lespedeza capitata.* This vicinity was studied also in the summer of 1904, and according to the best recollection of the writer, no such assemblage of plants was observed. It is entirely probable that the association has developed since that time. Willow seeds may easily have been blown in by the wind, and the seeds of the herbaceous plants may have been brought in in mud on the feet of birds, which were attracted by a temporary pool of water collected after rains.

Not far from this depression there was a similar one, but with sandy bottom. In 1904 it was occupied by *Polygonum acre, Hypericum mutilum, Cyperus rivularis,* and *Juncus tenuis.* In 1908, after a lapse of four years, the deepest part of the depression had been filled, so that the bottom was generally level. The prevailing vegetation is blue-grass, *Poa pratensis,* but a few relics of *Hypericum, Juncus,* and *Cyperus* still persist.

Just east of Havana, at the "Devil's Hole," there is another deep depression with a more luxuriant growth of vegetation. In the deepest part there is a small but dense thicket of *Salix longifolia.* Under the willows the sand is covered with a carpet of moss and decaying leaves, making a humus layer which must aid greatly in the absorption and retention of water. At the edge of the thicket is a narrow zone of *Bochmeria cylindrica, Ludvigia alternifolia,* and *Lycopus americanus.* These plants may be considered as a part of the *Salix* association but do not live within the thicket because of the weak light. Around the willows, and extending partly up the hill, is a dense growth of *Solidago graminifolia* and *Equisetum hyemale,* var. *intermedium,* constituting the *Solidago* association. The two alternate, *Equisetum* occupying about one third of the zone. Mingled with these are a few plants of *Cacalia atriplicifolia, Vernonia fasciculata,* and *Asclepias syriaca,* as well as a number of the usual blowsand plants, as *Paspalum setaceum, Cassia Chamaechrista, Cristatella Jamesii, Croton glandulosus,* var. *septentrionalis, Ambrosia psilostachya,* and *Monarda punctata. Eragrostis trichodes, Chrysopsis villosa,* and *Lithospermum angustifolium* also occur, but are rare. This zone has a vertical width of about six feet (2 m.). Near its upper (outer) margin are a number of old bunches of *Sporobolus cryptandrus* and a few of *Andropogon fur-*

catus and *Panicum virgatum*. These, as well as the appearance of the goldenrod, indicate that the zone is migrating up hill over the partially stabilized sand. The rounded contour of the willow thicket with the youngest plants at the edge, show that it is also enlarging and occupying successively higher levels. This movement is correlated with the development of the retentive layer of humus under the thicket, but the movement of the *Solidago*, already six feet (2 m.) above the willows, depends more upon the general vegetative activity of the plant itself.

These two associations, *Solidago* and *Salix*, may then be expected to appear in any deep blowout. Naturally the deeper ones only can support the willow, which requires a larger supply of moisture. This zonal relation of willow and goldenrod is by no means local, but may be observed in many localities in the eastern states. The absence of the goldenrod zone around the willows in the first depression described is merely one of those chance instances of distribution for which no explanation can be given. Possibly the presence of *Juncus acuminatus* indicates the first stage in its formation.

It is evident that with the establishment of the dense growth of *Solidago* the movement of the sand must cease, and it may be that it does not appear until the sand has first become static. In either case, if its depth is not sufficient to reach moist layers of sand the willow can not develop and the blowout will be occupied by *Solidago* alone. On the other hand, if the conditions are suitable for the growth of willows, the *Solidago* association can develop simultaneously around it. The willows therefore, requiring the deeper excavation, can not follow the goldenrod, but must appear before or with it. When both are established, the former becomes dominant because of its greater control of the physical conditions and tends to succeed the latter.

This condition of affairs is peculiar in two respects. First, the development of the dominant *Salix* association can not follow in time that of the minor *Solidago* association. Second, the general movement of the zones is centrifugal, extending progressively further up the sides of the blowout, and the direction of succession is apparently toward a hydrophytic climax.

It must not be presumed that in this case a hydrophytic climax will appear. It is probable that the water-retaining humus does not become thick enough to hold standing water, and it is still more probable that a new movement of sand from the west may overwhelm the whole association. As in another case already mentioned, there is at present no association in the region that could possibly be

referred back to this for its origin, indicating that all former associations of this type have sooner or later been destroyed.

THE POLYTRICHUM ASSOCIATION

In the Dixon area the hydrophytic series is carried further, and a new association, characterized by *Polytrichum juniperinum*, also appears. The *Solidago* and *Salix* associations are also represented. In all, six depressions show one or more of these associations and illustrate not only the successions between them but their development as well. For convenience they will be referred to by letters. These depressions are near the Northwestern tracks about four miles west of Dixon. Blowout *A* is on the north side of the track; *B* is near the track on the south side; *C* is east of the deposits of a large blowout south of the track; *D*, *E*, and *F* are in this blowout or its southern extension.

Blowout *A* is a shallow depression, but with rather moist sand. It is occupied mainly by a dense growth of *Solidago graminifolia*, with *Equisetum arvense*, *Carex* sp., and *Spiraea salicifolia* as accessory species.

Blowout *B* is smaller in width and length, but deeper and with steeper sides. On the outside there is a ring of *Solidago graminifolia* with an abundant growth of *Aristida tuberculosa*. The most abundant accessory species is *Lespedeza capitata*, and others of less frequency are *Andropogon furcatus*, *Cassia Chamaechrista*, and a few sterile grasses which could not be identified. *Aristida* and *Solidago* are almost equally abundant except at the inner margin, where the former is slightly in excess. This zone extends up the hillside to the typical bunch-grass and is rather sharply delimited from it. In the center of this ring is the *Polytrichum* association. The moss grows in dense mats, occupying all the surface in the deepest part of the depression. These mats are very thick and spongy and sink beneath the feet several inches. The dead stems grade off beneath into a thick, brown, moist, spongy layer of a somewhat peaty texture. The mats are sparsely occupied by solitary plants of the several accessory species. *Solidago graminifolia* is the most abundant of these and extends entirely across, but the plants are much smaller than in the association outside. The others are *Lycopus americanus*, *Hypericum majus*, *Salix pedicellaris*, and *Aster* sp. There are also a few depauperate relic bunches of *Panicum virgatum*. There is a narrow tension zone between the two associations, in which the mats of moss are less close and the stand of *Solidago* less pure. The moss is

encroaching upon the *Solidago*. There is a difference of about 1.5 feet (5 dm.) in the upper and lower levels of the *Polytrichum* zone, and the *Solidago* association is somewhat broader vertically. The deepest part is about 16 feet (5 m.) above the drainage level 200 yards (200 m.) away and all the intervening territory is sand. The mesophytic nature of the association must be due to the action of the moss in developing a retentive layer of humus, rather than to any feature of drainage.

Blowout *C* is small and flat and most of it is occupied by a dense carpet of *Polytrichum*, with many low shrubs of *Salix pedicellaris* and some seedlings of *Populus deltoides*. The surrounding zone consists chiefly of *Solidago graminifolia* and *Lespedeza capitata*. This blowout is about 12 feet (4 m.) above the drainage level and about 6 feet (2 m.) above the cultivated field just east of it. It is 14.5 ft. (4.8 m.) below the crest of the deposits of blowout *D* at the west.

D is a large blowout still active on the north, east, and west. A low oblong area enters the blowout from the southwest and is now almost entirely stabilized. Most of this represents a recent deposit of sand from the rear, but the deepest part, nearest the center of the blowout, is the extinct basin. It is now 11 ft. (3.3 m.) below the crest of the deposits. In this basin both the *Salix* and *Solidago* associations are now developing. The latter is represented by a plentiful growth of *Solidago graminifolia* and *Aristida tuberculosa*, with some *Juncus acuminatus*; the former by abundant young plants of *Salix longifolia*, with *Ludvigia palustris*, some small plants of *Panicum virgatum*, four or five plants of *Populus deltoides*, and four bunches of *Scirpus cyperinus*. The sand is wet and well covered with a layer of dead vegetable matter.

On pure sand back of this basin and 6-12 inches (1-3 dm.) above it is a mixture of the *Solidago* and *Polytrichum* associations. The ground is partially covered with dense or open mats of *Polytrichum*, with *Hypericum gentianoides, Rhexia virginica, Juncus acuminatus, Polygala sanguinea*, and seedlings of *Salix pedicellaris*. *Solidago graminifolia* and *Aristida tuberculosa* are abundant, but as usual are conspicuously smaller when growing on the moss mats. *Rhexia* may live in the middle of the mats, but *Hypericum gentianoides* grows only in the bare sand in the immediate vicinity of the moss.

Each of these parts of the blowout illustrates early stages in the development of the associations, before their zonal relations have been established. The *Salix* association apparently demands moist

sand and comes in only in the deepest part of the blowout. *Polytrichum,* on the other hand, may colonize in relatively dry sand, where it at once produces moist conditions by its dense growth.

Still farther in the rear and also somewhat higher is a deposit of sand representing a later stage in the refilling of the basin. It has been stabilized by *Panicum virgatum* and *Lespedeza capitata.* Besides these, *Solidago nemoralis, Hudsonia tomentosa,* and *Panicum pseudopubescens* indicate a reversion to bunch-grass. Over this whole area mats of *Polytrichum* are appearing. Some mats are large, confluent, and dense; others small, regularly circular, and with very small plants near the margin. These are coming in everywhere, even under the bunches of *Panicum virgatum* and *Panicum pseudopubescens,* or surrounding *Hudsonia tomentosa* or *Solidago nemoralis.* Coming up with it are many plants of *Solidago graminifolia, Aristida tuberculosa, Rhexia virginica, Polygala sanguinea,* and in the deepest parts a few plants of *Scirpus cyperinus.* On the larger and older mats these species are small or absent, and other species more characteristic of the association occur. These are *Salix pedicellaris, Viola lanceolata,* and *Spiranthes cernua.* A few depauperate plants of *Panicum pseudopubescens* persist even in the dense mats of the moss. Along the south and west margins of this area almost pure mats of *Polytrichum* extend to the very edge of the blowsand (Pl. XII, Fig. 1; XII, Fig. 2), reaching a height of three feet (9 dm.) above the *Salix* association already described. They are associated only with the three typical species just mentioned. Throughout this area *Solidago graminifolia* and *Aristida tuberculosa* occur, but they are most abundant on the bare sand between the mats. As the *Polytrichum* increases and finally occupies all the surface, these will be forced into a marginal zone, as in blowouts *B* and *C.*

THE SWAMP ASSOCIATION.

In the Dixon area, just south of blowout *D,* is a long north and south excavation (Pl. XIII, Fig. 1), with rather steep walls of bare sand on either side. These walls represent a partially stabilized windward slope, and are occupied by *Carex umbellata, Aristida tuberculosa, Panicum pseudopubescens,* and *Solidago nemoralis.* In the deepest parts are two ponds, *E* and *F,* surrounded by definite zones of vegetation. The bottom of the ponds is a black muck well mixed with sand. The water-level fluctuates with the weather. When visited in August it was one foot (3 dm.) above the basin of blowout *D,* 6.4 feet (2.1 m.) above the country to the east, and 16 feet (5.4 m.)

above the drainage level at the northeast. The inner zone of vegetation is characterized by *Scirpus cyperinus, Eleocharis obtusa, Ludvigia palustris, Juncus nodosus,* and a few relics of *Panicum virgatum.* Outside this is a regular but narrow zone of *Polytrichum,* with *Polygala sanguinea, Juncus acuminatus, Hypericum gentianoides,* and *Rhexia virginica.* Next is the zone of *Solidago graminifolia* with its usual associate *Aristida tuberculosa,* and, as accessory plants, *Rhexia virginica, Juncus acuminatus, Gerardia purpurea,* and *Polygala sanguinea.* Either of these outer zones may be absent for short intervals, but are usually very distinct.

The second pond, *F,* was almost dry when visited in August, 1908, and its mucky bottom was about 15 inches (4 dm.) below the water-level in pond *E.* Its vegetation had been badly destroyed by cattle.

On the windward slope near *E* a mat of *Polytrichum* is developing in a very shallow, flat depression three feet (9 dm.) above the water-level and one foot (3 dm.) above its nearest neighbors. It is surrounded by a large patch of *Hypericum gentianoides* extending one to ten feet beyond it.

From this detailed description it is seen that the vegetation of the foregoing series of depressions of the swamp formation comprises four associations of the following species.

1. The *Solidago* association. *Solidago graminifolia, Aristida tuberculosa, Equisetum arvense, Spiraea salicifolia, Carex* sp., *Polygala sanguinea, Gerardia purpurea, Juncus acuminatus, Rhexia virginica.* Accessory or relic species: *Stenophyllus capillaris, Lespedeza capitata, Andropogon furcatus, Cassia Chamaechrista.*

2. The *Salix* association. *Salix longifolia, Salix nigra, Populus deltoides.* Accessory or relic species: *Panicum virgatum, Scirpus cyperinus, Juncus acuminatus, Ludvigia palustris.*

3. The *Polytrichum* association. *Polytrichum juniperinum, Hypericum gentianoides, Salix pedicellaris, Aster* sp., *Lycopus americanus, Hypericum majus, Viola lanceolata, Rhexia virginica, Spiranthes cernua.* Accessory or relic species: *Polygala sanguinea, Panicum virgatum, Juncus acuminatus, Ludvigia palustris.*

4. The swamp association. *Scirpus cyperinus, Juncus nodosus, Eleocharis obtusa, Ludvigia palustris.* Relic species: *Panicum virgatum.*

The *Salix* and *Polytrichum* associations occupy parallel positions, but develop under different conditions. The former demands a considerable supply of moisture and is restricted to the deeper depressions, whereas the latter may develop at almost any level in the blow-

out. The appearance of the *Salix* association can not follow in time that of the *Solidago* association, as has already been explained. *Polytrichum* may colonize not only under the *Solidago* but also under a more xerophytic type of vegetation as well. Both indicate moist sand; the mosses by retention of moisture, the willows by retention and depth of position. Consequently each develops contemporaneously with the *Solidago* association, and in the early stages the associations are not differentiated. Later the *Solidago* association is forced to the outside.

In both cases the succession is in a xerophytic-hydrophytic direction. Nothing has been observed to succeed the *Salix* association, even in the oldest and deepest blowouts. The mats of *Polytrichum*, on the other hand, produce a peaty layer over the sand, which becomes so thick that it retains standing water and admits of the development of a pond society. These ponds must be held by a watertight bottom, otherwise their water would soon drain out through the sandy subsoil. As it is, they are conspicuously higher than the general level of the country. The zones surrounding the ponds move outward and upward and permit the continued growth of the pond. This is evidenced not only by the position of young mats of *Polytrichum*, but also by relic bunches of such typical sand plants as *Panicum virgatum*, now actually in the standing water. If continued far enough the increase of the pond might ultimately lead to the establishment of other associations, such as pondweeds or water-lilies. Its growth is retarded, however, by the gradual deposition of windblown sand, by the accumulation of soil by the aquatic plants, and by loss of water because of increased pressure on the mucky bottom. Most important of these is the deposition of sand, which will mix with the peat and eventually raise the level of the soil somewhat above the water-table. The later stages in the succession are probably similar to the meadows in the Kankakee area, except that the latter represent primary successions on a large scale, instead of secondary successions in a small area.

Succession of the Prairie Formation by the Forest

It was a matter of great interest to the first explorers and settlers in Illinois that so much of the surface was occupied by prairie, and that the forests were confined to certain physiographic divisions, especially the stream valleys. In seeking to account for this natural feature, the earlier generation of scientists, and to some extent even the modern ones as well, were influenced, or even prejudiced, by two

wrong ideas. In the first place, as they and their ancestors had lived for generations in a forested country, the forest came to be regarded as the only possible natural covering, and any other type of vegetation was considered extraordinary. In the second place, they did not at first recognize that the forests were everywhere encroaching slowly upon the prairies, or that the encroachment became measurable as soon as the prairie fires were checked. The prairie is not an extraordinary thing, to be explained only by some strange or fanciful causes; it owes its origin to ages of arid climate in the west and southwest (Harvey, *1908:* 84). The forest also owes its origin to ages of humid climate in the east and southeast (Adams, *1902*). These great climatic types acting upon the plant world through evolution and elimination, gradually developed the two extreme types of vegetation, each of which was especially adapted to its own environment. After the close of the glacial period migration of each of these types brought them in contact in Illinois and the neighboring states, and a struggle for supremacy began between them. The outcome is decided mainly by two sets of factors; first, the control of the environment by the vegetation, and second, the climatic conditions of temperature and rainfall. In the first case, the prairie vegetation, by virtue of its close sod, tends to prevent the proper germination and growth of the forest-tree seedlings (Harvey, *1908:* 86; Robbins and Dodds, *1908:* 35). Prairie fires, following the advent of man, also tend to restrict the growth of the forest. On the other hand, the forest has control of the light supply for the herbaceous layers and the well-established trees are resistant to fire. Above all, the climatic conditions are favorable to forest (Schimper, *1903:* 162-173; Transeau, *1905*). The balance has been in general in favor of the forest and it has advanced slowly upon the prairie.* The greatest speed of advance has been along the lines of least resistance, the watercourses, and has resulted in long strips of forest, paralleling the streams, and usually widest on the east side of streams or marshes where they were better protected from fire. In the sand regions the forest distribution is not regulated in that way, because of the absence of small streams, but it does show a possible relation to fires. Where the sand lies in disconnected ridges, separated by strips of moist or swampy ground acting as fire-breaks, as in the Havana, Ambov, and Kankakee areas, there is a good growth of forest on the higher ground. Where the sand lies in large continuous masses, as in the

*It is probable that at certain places and during certain periods the influence of fires has turned the balance in favor of the prairie, but this has not interfered with the general advance of the forest.

Oquawka and Hanover areas, there are large tracts of prairie. The Winnebago area lies protected on three sides by streams of considerable size, and is almost entirely forested, except the cultivated fields.

In the Havana area, there is a belt of forest along the Illinois river, and large forest masses at the south and north ends, particularly near Forest City and Kilbourne. In other parts of the territory the broader deposits of sand are usually prairie, and the forest is restricted to the narrow ridges. These extend north and south and mark the location of old sand-bars. In the Amboy area the distribution is similar, but the ridges run generally east and west. They have probably all been forested except those nearest the margin of the deposits. In the Oquawka area there is a belt of forest along the Mississippi river and another inland near the bluff line. These are connected by broad bands of forest which separate several areas of prairie. The Hanover area has a similar belt along the Mississippi, and a number of transverse strips extend inland. These have been partially cleared, but probably none of them crossed to the bluffs except at the extreme northern end. The Winnebago area was entirely forested except a few small areas of marsh and islands of prairie. It is difficult to estimate the proportion of the area covered with forest. It was probably considerably more than half in the Oquawka area, about a third in the Hanover area, and about a half in the Havana area.

The regular belt of forest along the rivers in the last three areas may be correlated with the effect of fire. The transverse bands across the area in the Hanover and Oquawka areas follow the most irregular portion of the surface, where the effect of fire was possibly limited. The large grove northwest of Hanover station, in particular, follows a line of steep-sided irregular dunes totally unlike the gently rolling prairie.

The encroachment of the forest is caused by the slow migration of the forest trees in every direction. The open structure of the bunch-grass does not prevent the proper germination of seeds or growth of seedlings as does the close sod of a normal prairie. Few species of trees, however, are able to withstand in their seedling stages the extreme conditions of the physical environment. These are especially the shifting nature of the sand, the hot surface layer, which may be almost totally dry to a depth of more than a decimeter, and the lack of protection against wind during the winter. Still another restricting influence is the absence of ready means of dispersal. The trees composing the early stages of the forest are oaks. Their heavy acorns have no means of dispersal except gravity and

the agency of animals. There are few animals to carry the acorns out on the prairie. The majority of such acorns are eaten, and many of the remainder decay. Some trees produce exceedingly heavy crops of acorns, which lie in layers an inch or two (3-4 cm.) deep beneath the tree, but of a large number examined, not one was sound. The life of a tree seedling is at best precarious, and in an unusual environment, with full exposure to wind and sun, few of them may be expected to survive. It is possible that some seasons are more favorable than others, and that after intervals of several years a succession of two or three favorable seasons may lead to a considerable extension of the forest. This condition has been described by Ramaley (*1908:* 30) and is probably of wide application.

Establishment of the forest makes at first very little difference in the environment. The trees are relatively far apart, and sufficient light comes through the foliage to permit the growth of many species of the original bunch-grass. The edge of the forest, therefore, shows, not a change in the flora but merely the addition of a few other species. There are at present few places where the contact between forest and prairie can be observed. Of these, the best is in the Hanover area (Pl. XIII, Fig. 2). The ground cover is the usual climax growth of the mixed consocies of bunch-grass, consisting particularly of *Koeleria cristata* and *Andropogon scoparius.* With these are *Boutcloua hirsuta, Aster linariifolius, Aster sericeus, Callirhoe triangulata,* and other common species. The sand is in apparently the same condition as upon the prairie. The fallen oak leaves have either blown away completely or have been collected in piles around fallen branches and in thickets of *Rhus canadensis,* var. *illinoensis.* There is none of the additional herbaceous species typical of the older established forest. In the Winnebago area there are a few small open spots within the forest, which represent the last stages of a prairie. In the first of these there are *Carex Muhlenbergii, Koeleria cristata, Liatris cylindracea, Lespedeza capitata, Viola pedata, Polygala polygama,* and *Artemisia caudata.* Oak seedlings one or two years old were also present. In a larger opening (Pl. XVII, Fig. 1) the prairie character is more obvious. The dominant species consist of a mixed growth of *Panicum Scribnerianum, P. perlongum, P. pseudopubescens, P. virgatum,* and *Carex Muhlenbergii.* Between their branches the ground is well matted with *Cladonia.* Some of the accessory species are *Tephrosia virginiana, Amorpha canescens, Lespedeza capitata, Solidago nemoralis, Asclepias amplexicaulis, Potentilla arguta, Accrates viridiflora,* var. *linearis, Viola pedata,* and *Ambrosia psilostachya.* There are no forest relics.

This fact, together with the pure yellow sand of which the substratum is composed, indicates that it never has been forested.

The boundary between the forest and prairie differs from the usual forest margin in the absence of a tension zone and a definite vegetation. Thickets of hazel, of sassafras, or of sumach, which surround the typical Illinois forests, are absent. There is no sharp distinction of flora within and without the forest edge, and no massing of a large number of species near the margin. The whole succession is of a type rarely mentioned or described, in which there is at first no essential change in the environment.

There is no first-hand evidence concerning the rate at which the extension of the forest is proceeding. The first settlements were usually made near the edge of the forest, where clearing and cultivation at once stopped any advance. Historical evidence is not always of value, because complete dependence can not be placed on statements of a scientific nature made by travelers or casual observers. A note by Patrick Kennedy (Imlay, *1797:* 508), however, is suggestive, and probably at least partially correct.

"About sun-set we passed the river Demi-Quian.* It comes in on the western side of the Illinois river (165 miles from the Mississippi); is 50 yards wide, and navigable 120 miles. We encamped on the south-eastern side of the Illinois river, opposite to a large savanna, belonging to, and called, the Demi-Quian swamp. The lands on the southeastern side are high and thinly timbered; but at the place of our encampment are fine meadows, extending farther than the eye can reach, and affording a delightful prospect. The low lands on the western side of the Illinois river extend so far back from it, that no high grounds can be seen. Here is plenty of buffalo, deer, elk, turkies, etc."

Kennedy's whole narrative seems reliable, and we may believe that at least in some directions his camp commanded an uninterrupted view of the prairie. At the present time, however, the marginal belt of timber along the river in the vicinity of Havana is from 100 yards to a quarter of a mile (100 to 500 m.) wide, while the fringing woods along Quiver creek and large tracts of black oak completely cut off a view of the prairies. If Kennedy's statement is correct, then large areas of timber have developed within the last century.

It is difficult to explain the migration of the oaks. Their normal method is by gravity, which tends to scatter the acorns to a little distance as they fall from the trees. By this method alone the mi-

* The Spoon river, which empties into the Illinois opposite Havana.

gration even of a few miles would require thousands of years. The animals which feed upon acorns do not usually carry them a long distance, and those which are carried away are generally eaten. The acorns are produced in large numbers and lie thickly on the ground beneath the trees, but, as reported also by Britton (*1903:* 578), most of them are not viable. Reid (*1899:* 29) reports that in England rooks carry acorns to some distance and that isolated young plants may be found at a considerable distance from fruit-bearing trees. It is his idea (*1899:* 31) that the "accumulated accidents of some thousands of years" are sufficient to explain the distribution of oaks in England. In the Illinois sand region seedling oaks are always few in number and are never found on the prairie. Accidents can not be invoked here to explain a migration so regular, so continuous, and apparently so rapid, and the whole question must be left unanswered.

When once established the forest is permanently dominant, unless destroyed by man or by some exceptional physiographic changes. In the former case there may be a temporary reversion to the bunch-grass association. One such case was observed near Forest City, in the Havana area. The ground was occupied by a good growth of bunch-grasses, including *Panicum pseudopubescens, Leptoloma cognatum, Sorghastrum nutans, Andropogon scoparius, Tridens flavus, Boutcloua curtipendula, Paspalum setaceum,* and *Carex Muhlenbergii.* There were thickets of *Rhus canadensis,* var. *illinoensis,* and mats of *Opuntia Rafinesquii,* and numerous interstitial plants of *Cassia Chamaecbrista, Ambrosia psilostachya,* and *Monarda punctata.* None of the perennial group was present. Numerous young plants of *Quercus marilandica* and *Quercus velutina* were appearing, indicating the approaching end of the bunch-grass association.

Within the forest may be distinguished two well-marked associations, related to each other by a clearly defined order of succession, and differing in their habitat and component species. Of these the pioneer is the black oak association.

The Forest Formation

the black oak association

The associations of the forest formation are fewer in number than those of the prairies. The first of them in order of succession and the most typical of the sand region is the black oak association. (Pl. XIV, Figs. 1, 2; XV, Figs. 1, 2; XVII, Fig. 1). It is found

in each area studied, except the Dixon area, which is entirely without forest. In the others most of the forested portion is covered with this type. It has also a wide distribution beyond Illinois and is mentioned under the same or different names by several writers.

Cowles described the association (*1899:* 379-382) at the head of Lake Michigan under the name of oak dunes. Nearly all the herbaceous species mentioned in his short list occur also in Illinois. Jenning's *Quercus velutina-imbricaria* Forest Formation of Cedar Point (*1908:* 300) is similar, but includes many plants which represent a somewhat later stage in succession. The oak-pine-sassafras society of Livingston (*1903:* 40-42) in Kent county, Michigan, is also much like the Illinois association, but contains many relic specimens of the pine forests which preceded it in order of succession. Britton (*1903:* 578, 579) mentions the occurrence of black oak on the sand-plains of Connecticut. He did not differentiate a particular association, but it is very probable that at least some of the vegetation is of this type.

In each of the extralimital localities mentioned the dominant tree is the black oak, while the herbaceous vegetation shows a considerable variation. This is because of the differences in the neighboring associations, from which many species find their way into the black oak forest. Warming (*1909:* 146) has termed such conditions *geographical variations* of an association. With our present knowledge of plant associations it is not clear how much weight should be given to these variations in floristic composition.

The association is characterized by the black oak, *Quercus velutina,* and in the Havana and Oquawka areas also by the black-jack oak, *Quercus marilandica.* Both species have the same general habit and live together in various proportions, but with the black oaks usually more numerous. The trees are sometimes close and crowded, sometimes wide apart. Old forests, whose origin probably dates back to the period of prairie fires, and forests on steep dunes are usually open, with trees 5-20 yards (5-20 m.) apart. Young forests of recent development or those protected by swamps are usually dense, with an average distance of 3-15 ft. (1-4 m.) between the trees (Pl. XIV, Fig. 1). Densest of all are the young groves which have recently sprung up in abandoned fields and clearings. In these the trees stand at close intervals and the trunks are covered with stiff, crooked, dead branches down to two or three feet (1 m.) from the ground (Pl. XIV, Fig. 2), making them almost impassable. The older and more open forests are especially characterized by bare crooked trunks with divergent branches at a height of 6-12 ft. (2 to 4 m.).

This gives the grove an aspect not unlike an old apple orchard (Pl. I, Fig. 1). The absence of low branches is possibly due to the action of fires, since natural pruning does not seem very effective. The trees are uniformly low, rarely exceeding 35 ft. (10 m.) in height or one foot (3 dm.) in diameter. In the Havana and Oquawka areas the bitter nut hickory, *Carya cordiformis,* also occurs.

Since the oak trees are the dominant members of the association, they determine to a large extent the ecological nature of the forest floor, and many peculiarities in the growth or distribution of the herbaceous or shrubby members are directly correlated with the character of the forest. In the young oak woods the ground is bare sand, covered by leaves only around fallen branches or sumach thickets. In forests of greater area or wider extent there is a greater accumulation of leaves, leading to the formation of a thin layer of leaf-mold. The thickness of the leaf-mold is a crude index to the age of the forest. The surface layers of sand thus gradually attain a greater capacity for holding water and a greater amount of organic matter. Even in the young forests the surface layers of sand are in general moister than on the prairie, because of the lower intensity of light and the slight exposure to the wind. The intensity of the light is much reduced, although the foliage of the trees is less dense than in the more typical forests of the state. These two features, soil and light, are the most important environmental factors in the association.

The herbaceous and shrubby vegetation, after a few ubiquitous weeds and naturalized plants are excluded, may for convenience be referred to two groups. The prairie group includes those species more abundant in and more typical of that formation, and the forest group includes species more characteristic of the forest and rare or absent in the prairies. It is impossible, but also unnecessary, to draw a sharp line between the two groups. It is evidently the light relation that determines the distribution of the members of the prairie group, since they occur in leaf-mold in the more open woods, but are absent from dense woods with a pure sand substratum. The leaf-mold, on the other hand, seems to be of chief importance to the true forest species, since they frequently occur in open woods with a thin layer of mold on the surface, but seldom in shady woods with a sand floor. Dense woods without leaf-mold are therefore very poor in species and individuals, while the most luxuriant herbaceous vegetation is developed in relatively open woods with a thin layer of mold.

The species of the prairie group persist within the edge of the forest, and are at first dominant. Farther back from the margin the prairie species may include both invaders from the bunch-grass

and relics of a former prairie occupation. It is always difficult and usually impossible to distinguish the two. It may be assumed that most of the annuals and the more abundant perennials with effective means of dispersal are invaders, while rare or solitary perennials are relics. *Aster sericeus* is one of the most reliable examples of this type. As the forest increases in density, the sun-loving prairie species become more and more restricted to the small openings between the trees (Pl. XIV, Fig. 2). There the number and character of the species vary very regularly with the size of the opening. For illustration, in the Oquawka area openings 12-15 ft. (4-5 m.) across usually contain *Opuntia Rafinesquii* and *Rudbeckia hirta,* while others of twice the diameter may have in addition *Panicum pseudopubescens, Carex Muhlenbergii,* and *Bouteloua hirsuta.* In general, the perennial members of the group extend farther into the shade, and the interstitial annuals are more intolerant; few species appear, and they are usually limited to the larger openings between the trees. This feature of distribution is probably correlated with the duration of life of the plants, and the demands of their seedlings for certain definite light conditions. Some species do not occur beyond the more open woods or the larger open spots. Such are *Petalostemum purpureum, Pentstemon hirsutus, Tradescantia reflexa, Lespedeza capitata, Lithospermum Gmelini, Viola pedata,* and many others. Some species grow well and reach a normal size in the sun, while in the shade they are stunted or sterile. Shade plants of *Coreopsis palmata* are weak and lax, with thin divaricately lobed leaves; *Physostegia denticulata* is weak and thin-leaved, contrasting sharply with the stout, thick-leaved form in full sun; *Tephrosia virginiana* grows with single stems instead of dense bunches; the bunch-grasses are loose and lax, and tend to lose their bunch habit. *Andropogon furcatus* and *A. scoparius* are more tolerant than the other bunch-grasses, but in the shade they lose their bunch habit completely, sending up single culms which have a few long spreading leaves and are always sterile. *Rudbeckia hirta* and *Poa pratensis* seem to have about the same light requirements. Both are found only in the more open woods or in sunny places, and are very frequently associated. Notwithstanding the limitations in their distribution, a few of these plants play an important part in the composition of the association, and are almost as characteristic of the forest as some members of the forest group proper. They are *Lithospermum Gmelini* and *Rudbeckia hirta,* because of their conspicuous showy flowers, *Tephrosia virginiana,* because of its bunch habit, and *Lespedeza capitata,* because of its great frequency and abundance. These four occur in every area of the association.

Seventy-one species may be regarded as typical of the forest rather than the prairie, and of these, nineteen represent pioneers in the succession of another, more mesophytic, type of forest, leaving fifty-two to characterize the black oak association.

The most distinctive feature of the flora is the large proportion of perennial herbs. Thirty-nine species, or 75 per cent. of the total, belong in this general group. Contrasted with the same group in the bunch-grass association, the chief difference is in the smaller number of bushy forms, a type which seems to belong primarily to the more xerophytic prairie formation. The bushy perennials of the oak forest are almost without exception more abundant in and more characteristic of the bunch-grass association. *Callirhoe triangulata* and *Asclepias tuberosa* send up several ascending stems from a common base; *Phlox bifida* is divergently branched and may assume a rounded shape; *Helianthemum majus* has erect stems which frequently grow in clusters. Nearly all of these plants live also in the bunch-grass association. By far the greatest number of species have erect, simple or sparingly branched stems, without a large number of basal leaves, growing singly or in small loose clusters. *Pteris aquilina* lives in large patches, spreading by its rhizomes, and *Pedicularis canadensis* has the same habit on a small scale. *Fragaria virginiana,* var. *illinoensis,* and *Potentilla canadensis* are also gregarious, spreading by runners. *Synthyris Bullii* has a basal rosette of large suborbicular leaves which are closely appressed to the ground.

A considerable number of species belonging to the interstitial group of the prairie associations live also in the forest, but are limited usually to sunny places or the more open woods. Only four characteristic species of the forest have this habit, and these plants are neither common nor widely distributed. They are *Anychia polygonoides,* in the Hanover, Havana, and Oquawka areas, *Castilleja coccinea,* in the Winnebago area, *Gnaphalium polycephalum,* in the Oquawka and Amboy areas, and *Krigia virginica* in the Havana area. From an ecological standpoint, this group is of very slight importance.

Shrubs are much more abundant in the forest than upon the prairie. *Rhus canadensis,* var. *illinoensis* is the most abundant and grows in irregular thickets, seldom exceeding two feet (5 dm.) in height, but from 3-30 ft. (1-10 m.) wide. It was not observed in the Winnebago or Amboy areas, where its place is taken by the equally abundant *Salix tristis* growing in thickets of the same general structure. *Ceanothus americanus* is found in all five areas and is locally abundant. *Rosa humilis* is common in the Hanover and Winnebago areas. *Rhus glabra* is occasional and a single individual of *Pyrus americana* was found in the Winnebago area.

One of the most noteworthy plants is a species of *Geaster,* which is abundant in each of the five areas, especially in open woods or near the edge of the forest.

Although the total number of species in the association is large, the number per unit of area is scarcely greater than in the prairie. Counts of a series of quadrats each two meters square, in the Winnebago area, showed an average of 6.5 species per quadrat. The forest there was rather open, with a thin deposit of mold, and the conditions for plant life near the optimum. In the whole field of about twenty acres (8 hectares) 32 species occurred. The number of species in the whole association is large, as might be expected in a type of such wide distribution and extent, but less than half of the total live in any one of the five areas examined. The small number in any individual station and the large number for each quadrat produce a monotonous uniformity throughout the association and prevent the recognition of definite consocies.

The following list gives the ecological grouping of the component species.

A. Species typical of the black oak association

1. Trees:

Quercus velutina
Quercus marilandica
Carya cordiformis

2. Perennial herbs:

Pteris aquilina
Smilacina stellata
Comandra umbellata
Fragaria virginiana, var. *illinoensis*
Potentilla arguta
Potentilla canadensis
Lupinus perennis
Desmodium illinoense
Euphorbia corollata
Callirhoe triangulata
Lechea sp.
Helianthemum majus
Zizia aurea
Asclepias tuberosa
Asclepias amplexicaulis
Asclepias verticillata
Physostegia denticulata
Scrophularia leporella
Pentstemon grandiflorus
Synthyris Bullii
Gerardia grandiflora
Pedicularis canadensis
Galium pilosum
Liatris scariosa
Solidago speciosa, var. *angustata*
Solidago nemoralis
Aster azureus
Rudbeckia hirta
Helianthus occidentalis
Helianthus strumosus
Artemisia caudata
Cacalia atriplicifolia

Apocynum androsaemifolium
Phlox bifida
Monarda fistulosa
Monarda mollis
Krigia amplexicaulis
Hieracium longipilum
Hieracium canadense

3. Shrubs:

Salix tristis
Rosa humilis
Pyrus americana
Rhus glabra
Rhus canadensis, var. *illinoensis*
Ceanothus americanus

4. Annuals and interstitials:

Anychia polygonoides
Castilleja coccinea
Gnaphalium polycephalum
Krigia virginica

B. Species more typical of the prairie associations

Andropogon furcatus
Andropogon scoparius
Sorghastrum nutans
Leptoloma cognatum
Paspalum setaceum
Panicum virgatum
Panicum perlongum
Panicum Scribnerianum
Panicum pseudopubescens
Stipa spartea
Aristida tuberculosa
Sporobolus cryptandrus
Calamovilfa longifolia
Koeleria cristata
Bouteloua hirsuta
Tridens flavus
Cyperus filiculmis
Carex pennsylvanica
Carex Muhlenbergii
Tradescantia reflexa
Commelina virginica
Rumex Acetosella
Polygonella articulata
Talinum rugospermum
Anemone cylindrica
Lepidium virginicum
Tephrosia virginiana
Lespedeza capitata
Strophostyles helvola
Polygala polygama
Crotonopsis linearis
Euphorbia Geyeri
Ceanothus americanus
Hudsonia tomentosa
Viola pedata
Opuntia Rafinesquii
Oenothera rhombipetala
Acerates viridiflora
Acerates viridiflora, var. *lanceolata*
Lithospermum Gmelini
Teucrium canadense
Scutellaria parvula
Monarda punctata
Physalis heterophylla
Physalis virginiana
Linaria canadensis
Pentstemon hirsutus
Ruellia ciliosa
Diodia teres
Specularia perfoliata
Liatris cylindracea

Arabis lyrata
Polanisia graveolens
Cristatella Jamesii
Cassia Chamaechrista
Baptisia bracteata
Amorpha canescens
Petalostemum candidum
Petalostemum purpureum
Aster sericeus
Aster linariifolius
Antennaria sp.
Ambrosia psilostachya
Coreopsis palmata
Artemisia caudata
Senecio Balsamitae

C. Forest species, typical of succeeding associations

Polygonatum commutatum
Smilacina racemosa
Smilax herbacea
Smilax ecirrhata
Smilax hispida
Populus grandidentata
Corylus americana
Silene stellata
Anemone virginiana
Ribes gracile
Rubus occidentalis
Prunus virginiana
Rhus Toxicodendron
Vitis vulpina
Psedera quinquefolia
Cornus Baileyi
*Monotropa uniflora**
Fraxinus pennsylvanica, var. *lanceolata*
Eupatorium serotinum
Prenanthes alba

D. Ubiquitous weeds and naturalized species

Poa pratensis
Poa compressa
Juncus tenuis
Chenopodium album
Saponaria officinalis
Oxalis corniculata
Oenothera biennis
Asclepias syriaca
Verbena stricta
Nepeta Cataria
Leonurus Cardiaca
Solanum carolinense
Solanum nigrum
Verbascum Thapsus
Erigeron ramosus
Achillea Millefolium
Lactuca canadensis

E. Species of doubtful position in the sand region

Rumex altissimus
Solidago serotina
Silphium integrifolium

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*Not observed in the bur oak association, but, from its general habit, probably more typical there.

SUCCESSIONS FROM THE BLACK OAK ASSOCIATION

In Illinois, succession between different types of forest is usually caused by the disturbance of some feature of the physical environment by physiographic changes. It therefore becomes possible to correlate the succession of forests with the physiography (Cowles, *1901*). In the sand areas of the state, however, physiographic processes are primarily not concerned, and the whole process is due to the reaction of the plant upon its habitat, by which there is developed a different habitat, adapted to a different type of vegetation. The chief feature of the vegetation by which these environmental changes are caused is the general density of the plant covering. This leads to the partial exclusion of sunlight, heat, and moisture from the soil, and to the addition every autumn of a large quantity of vegetable matter. In this way the soil moisture is conserved, the transpiration of the plants is diminished, and a layer of leaf-mold is slowly formed. The leaf-mold also aids in the conservation of moisture in the soil and at the same time increases its capacity for holding water. All of these changes go on simultaneously, and each is correlated with the others. The whole is in a mesophytic direction and, as a result, the xerophytic black oak association is succeeded by vegetation of a more mesophytic type, consisting of at least two, and possibly more, distinct associations. For the present, that of the Winnebago and Amboy areas will be considered as one, termed the bur oak association, and that of the Hanover, Havana, and Oquawka areas as another, the mixed forest association.

THE BUR OAK ASSOCIATION

In the Winnebago area the sand is distributed in irregular ridges, separated by irregular depressions of various sizes. The latter are occupied by an association characterized by bur oak, *Quercus macrocarpa,* and white oak, *Quercus alba,* together with a distinct type of herbaceous flora. None of the narrower upland ridges has as yet been succeeded by the bur oak association, although some show indications of it in the presence of scattered plants of choke-cherry, *Prunus virginiana,* black cherry, *Prunus serotina,* and hazel, *Corylus americana.* The bracken fern, *Pteris aquilina,* also becomes more abundant near the bur oak association (Pl. XV, Fig. 1), and its presence in large quantities may in some degree be considered as one indication of the approaching succession. On some ridges there is a well-defined zone of *Pteris* along the slopes, extending neither into the xerophytic black oak timber above, nor into the mesophytic bur

oak forest below. This type of distribution has been observed only on the narrower ridges, along the crests of which the xerophytic habitat is more emphasized and where the accumulation of humus takes place more slowly. On the broader uplands *Pteris* is usually common. Some of the latter show a transition to the bur oak type in the presence of *Pyrola elliptica, Amphicarpa Pitcheri, Vitis vulpina,* and *Agrimonia mollis,* typical members of the latter association. On the slopes from the black oak into the bur oak association there is usually a well-defined tension zone (Pl. XV, Fig. 2) where the plants of both groups mingle. Among these the most abundant are *Pteris aquilina* and *Smilacina stellata* of the black oak association and *Geranium maculatum* and *Prunus virginiana* of the bur oak.

The sharpness of the tension line, coupled with the slow development of the dominant species of the two associations, indicates a condition approaching an equilibrium between the two associations. Their common boundary on the steeper slopes seems to depend upon the water content of the sand as influenced by the height above the water-table, while on the broader uplands the incipient succession may depend not only upon the depth of the water-table, but to a greater extent upon the increase in water capacity through the development of humus. The present location of small ponds in the sand deposits shows that the actual depth of the water-table is several yards, and in all probability too great to explain the sharp tension line already noted. Its origin must accordingly be referred back to a past condition in which the general water-level was higher. Trees of *Quercus velutina* in the lower portions of the bur oak association are very few in number and usually small in size, showing that they are not relics, but recent sporadic invaders, and there is an unusually small number of herbaceous relics. In the upland portions of the bur oak association relic trees of black oak are numerous and frequently of large size, while many relic herbaceous species also occur. Throughout the black oak association pioneers of the bur oak group are well represented, as is shown by the list given in the discussion of the former association. All these peculiarities lead to a choice of two conclusions: the depressions have never been occupied by black oak, or the succession by the bur oak has been extraordinarily complete. Further evidence leading to the acceptance of the first alternative is afforded by conditions in the Amboy area and to some extent also in the Kankakee area.

In the Amboy area the sand lies in similar ridges mostly parallel to Green river and not over 60 feet (20 m.) above it. The inter-

vening valleys are for the most part filled with extensive deposits of muck overlying sand and occupied by swamp vegetation, with *Iris versicolor, Typha latifolia, Rhexia virginica, Houstonia coerulea, Populus tremuloides,* and other species of similar habitat preferences. Outside these depressions, and accordingly above them, lies the bur oak association, above which in turn is the black oak association, occupying the crests of the ridge. In every case the bur oak type is characteristic of the more mesophytic sand near the water-level. According to all established principles of succession the drainage of the intervening swamps would cause a downward migration of the bur oak association, provided other features of the environment were favorable to it. It is, of course, hardly probable that the bur oak would extend very far out upon the deposits of muck. If the swamps were composed of sand instead of muck, it is very probable that the whole area would be occupied by the bur oak association as rapidly as the lowering of the water-level permitted. In the Kankakee area the interdunal depressions are occupied by meadows, which are doubtless very similar to the Amboy swamps, having a number of species in common, and probably representing a further stage in the succession on muck or peat. The ridges are all covered with forest, but in the short trip made through the area the distinctions made between the black oak and bur oak associations were not recognized.

The whole leads to the first alternative mentioned, that the depressions in the Winnebago area have never been occupied by the black oak association, and that the bur oak association, which now occupies them, represents the present culmination of a past hydrophytic to mesophytic succession, which has been so far completed that scarcely a trace of it is now in existence.

This conclusion is supported by the presence of a single small pond occupying a depression in a partially cleared field. The few plants remaining indicate that the surrounding vegetation was of the bur oak type. The swamp vegetation at its margin is scanty, consisting of *Scirpus validus* and *Steironema lanceolatum,* outside of which are successive zones of *Populus tremuloides* and *Solidago graminifolia.* Further details were not noted.

The development of the muck soil in the depressions of the Amboy and Kankakee areas and its absence in those of the Winnebago area must also be explained. The latter areas are essentially fluviatile; their depressions are not far above the beds of the Green and the Kankakee rivers, respectively, and the lowering of the water-level is entirely dependent upon changes in the river level and upon deposi-

tion of soil. A slow change in the water-level, for such it must have been along these comparatively sluggish streams, would permit the long-continued existence of swamps and the consequent accumulation of large deposits of muck. In the Winnebago area, on the other hand, the deposits lie many feet above the Rock, Sugar, and Pecatonica rivers; swamps would be of short duration and the accumulation of muck would not take place. Consequently, the depressions have been occupied almost entirely with the bur oak association, with the exception of the single pond already mentioned. of the hydrophytic extreme is, as usual, chiefly due to changes in the water factor, while that of the xerophytic extreme is in this case

The development of the bur oak association represents, therefore, another case of the interpolation of a mesophytic mean association between a hydrophytic and a xerophytic extreme. The succession caused primarily by the development of humus. The whole probable successional history is indicated upon the diagram (Fig. 6.) showing the relation of the various associations.

The preceding statements concerning the development of the bur oak association following the swamp vegetation does not imply that it was the first type of forest to appear. On the other hand, there is some fragmentary evidence that an entirely different forest association preceded it.

Within the bur oak association (Pl. XVI, Fig. 1), *Quercus macrocarpa* is everywhere the prevailing tree. In the Amboy area, it was the only arborescent species in the small areas examined. In the Winnebago area it is mixed with white oak, *Quercus alba,* and shellbark hickory, *Carya ovata.* The former composes 25-50 per cent. of the whole, while there is seldom over 2 per cent. of hickory. The trees are larger and straighter than those in the black oak association, but still much inferior to those of their own species growing on a more fertile soil. A large number of shrubs form a second layer beneath them, and are often aggregated into dense thickets. *Prunus serotina, Prunus virginiana,* and *Corylus americana* are by far the most abundant, with several other occasional species. Lianes are not common, and consist of scattered individuals of *Vitis vulpina, Smilax hispida,* and *Rhus Toxicodendron,* with a few other species of less importance.

The forest cover is dense and the light diffuse. This prevents the growth of most grasses, except where the forest has been partially cleared. The ground cover is composed chiefly of a dense luxuriant growth of herbaceous plants. They are of a larger average size and much more mesophytic appearance than those of the black oak ridges.

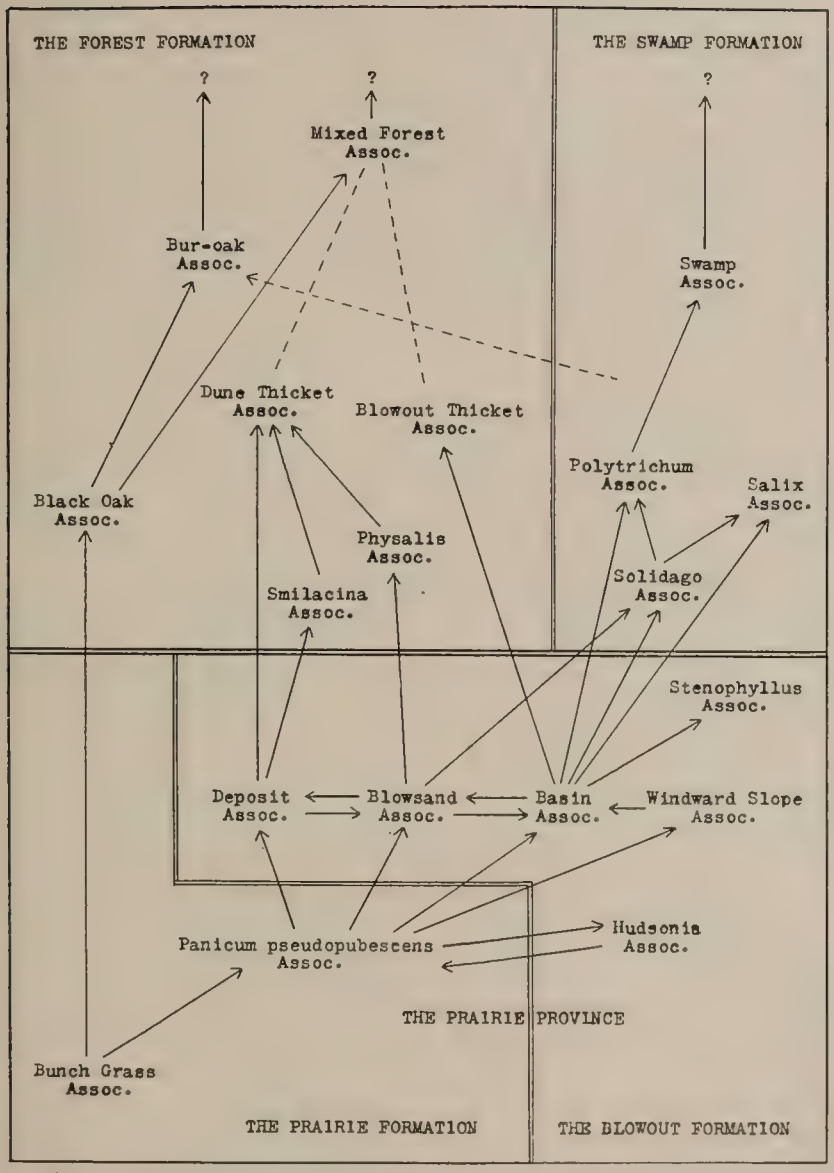

Fig. 6. Diagram showing the plant associations of the inland sand deposits of Illinois, and the principal successions between them.

Although comparatively few in number, their distribution is remarkably uniform, so that the various areas occupied by the association are strikingly similar in their vegetational appearance. On the uplands, it is more or less mixed with relics of the preceding black oak association.

An association greatly resembling this, and possibly identical with it, occupies in the Winnebago area the upland areas of clay overlying limestone, and indicates that, in the future development of the vegetation, the associations on sand and clay will become gradually similar. This is in accordance with the views of Cowles (*1901:* 7), that all the vegetation of a region "is tending toward an ultimate common destiny."

The specific composition of the association is shown by the following list.

A. Species characteristic of the association

1. Trees:

Quercus macrocarpa
Quercus alba
Carya ovata

2. Smaller trees and shrubs:

Populus tremuloides
Populus grandidentata
Corylus americana
Rubus idaeus, var. *aculeatissimus*
Rubus occidentalis
Prunus serotina
Prunus virginiana
Cornus Baileyi

3. Lianes:

Smilax herbacea
Smilax ecirrhata
Smilax hispida
Rhus Toxicodendron
Vitis vulpina
Psedera quinquefolia
Lonicera Sullivantii

4. Herbs:

Botrychium ternatum, var. *intermedium*
Botrychium virginianum
Polygonatum commutatum
Smilacina racemosa
Cypripedium parviflorum, var. *pubescens*
Silene stellata
Arenaria lateriflora
Heuchera hispida
Agrimonia mollis
Desmodium grandiflorum
Amphicarpa Pitcheri
Geranium maculatum
Circaea lutetiana
Sanicula canadensis
Pyrola elliptica
Dodecatheon Meadia
Veronica virginica
Galium concinnum
Prenanthes alba

B. Species more typical of preceding associations

Pteris aquilina
Poa pratensis
Tradescantia reflexa
Salix tristis
Quercus velutina
Fragaria virginiana, var. *illinoensis*
Rosa humilis
Amorpha canescens
Euphorbia corollata
Ceanothus americanus
Apocynum androsaemifolium
Monarda mollis
Synthyris Bullii
Gerardia grandiflora
Pedicularis canadensis
Antennaria sp.
Helianthus strumosus
Coreopsis palmata
Cacalia atriplicifolia

THE MIXED FOREST ASSOCIATION

In the Hanover, Oquawka, and Havana areas the succession from the black oak association is dependent primarily upon a general and gradual increase in the water content of the sand and a corresponding decrease in the light, without the concurrence of historical factors as in the two areas previously described. The succeeding vegetation is derived wholly from the surrounding associations. Since other types of vegetation are developed best near the rivers which border these sand areas, invasion begins near the river and gradually extends back toward the center of the sand deposits, so that the most advanced stages in the succession are always found near the river. The development of this succession is greatest in the Havana and least in the Hanover area; a feature which is perhaps correlated with the general southeastern origin of the forest formation.

In the Havana area, as in the Winnebago deposits, the narrower ridges of sand are the last to be affected by this succession, while the broader ridges or those near the river generally show some indication of it. Certain species are soon recognized as the normal pioneers in the succession, and while their order of appearance is not constant, their presence is always connected with the development of a thin, fibrous layer of leaf-mold over the surface of the sand. It is frequently possible to observe nearly all stages in the succession in a distance of a mile, passing from the edge of the forest toward its center. In some places, adjacent ridges of sand represent different stages of the succession, and permit an easy comparison of the vegetation. This is especially well shown on the first two forested ridges east of Havana, about two miles (3 km.) from that city. The first of these represents an advanced stage of the succession, while the second is occupied by a nearly typical black oak association.

Excluding the two species of oaks, the ridges have 29 and 31 species, respectively, of which only ten are common to both. This gives a community coefficient (Jaccard *1902:* 351) of 0.200, indicating at once the great floral dissimilarity. There are, on the other hand, thousands of acres still occupied by the black oak association, with as yet no indication of the approaching succession.

Rhus canadensis, var. *illinoensis, Tephrosia virginiana,* and *Opuntia Rafinesquii* are the chief species concerned in accumulating fallen leaves for conversion into leaf-mold. With the simultaneous decrease in light, the succession begins, and occasional plants of *Polygonatum commutatum* and *Silene stellata* appear as pioneers. *Agrimonia mollis* comes in somewhat later, and young plants of three lianes appear. These are *Vitis vulpina, Rhus Toxicodendron,* and *Psedera quinquefolia.* The last is especially common and valuable as a succession index. Its long, slender stems trail for several feet along the ground, unless by chance they encounter a tree trunk to climb. *Rhus Toxicodendron* seldom trails, but usually grows directly at the base of some tree. Following these six species, which are easily recognized as pioneers, a number of others appear in irregular order. The arborescent flora remains essentially the same, except for occasional trees of *Celtis occidentalis* or *Prunus serotina,* or, near the river, *Quercus rubra, Quercus macrocarpa, Juglans nigra, Ulmus americana, Morus rubra,* and *Gymnocladus dioica.* The undergrowth is frequently dense, with numerous thickets of shrubs, and the herbaceous growth is tall and luxuriant. The following additional species are especially characteristic:

Asparagus officinalis
Smilacina racemosa
Smilax herbacea
Dioscorea villosa
Anemone virginiana
Ribes gracile
Celastrus scandens
Oenothera biennis
Sanicula canadensis
Cornus Baileyi
Asclepias phytolaccoides
Lappula virginiana
Scrophularia leporella
Galium concinnum
Eupatorium purpureum
Eupatorium urticaefolium

It will be noted that a majority of these species have unusually efficient means of seed dispersal. When an association develops *de novo* some distance from the nearest existing area of it, the most mobile species may naturally be expected to appear first, while the less mobile species follow after greater intervals of time. The species in the preceding list accordingly represent the mobile pioneers of an association, the usual dominant species of which have as yet not ap-

peared. Near the Illinois river there are some rather extensive sand fields occupied by a forest characterized particularly by bur oak and white oak, with several other arborescent species, such as red oak, *Quercus rubra,* elm, *Ulmus americana,* hackberry, *Celtis occidentalis,* and white ash, *Fraxinus americana.* This probably represents the complete succession, the beginning of which has been indicated above. Intermediate stages, however, have not been observed.

In the Oquawka area the succession is found only on the long dunes nearest the river. The first indication of it is given by *Silene stellata, Polygonatum commutatum,* and *Psedera quinquefolia,* which are followed by a number of additional species, including several trees. The whole leads to the highest type of mesophytic forest (Pl. XX, Fig. 2, background) that occurs on the sand deposits.

The succession is best seen along the dune nearest the river, north of the town of Oquawka, and may be traced through various stages from north to south for a distance of about 1.5 miles (2 km.). This dune has a maximum height of about 100 feet (30 m.), indicating a very strong and continued wind action at some time in the past. It is now completely covered with trees, and the surface layers of sand are well mixed with organic matter. At the north end a bayou of the Mississippi lies at its base, and the margin of the water is marked by a line of elms and willows, with *Rumex verticillatus, Physostegia virginiana,* and other species of hydrophytic tendencies. *Equisetum hyemale* is the only one of these which extends much above the water-level, where it mingles with the usual sand-dune species. Along the north end of this ridge the prevailing trees are *Quercus velutina* and *Quercus marilandica,* with occasional trees of *Quercus rubra,* especially on the lower part of the slope. Besides the pioneer herbaceous species mentioned above, there are also *Strophostyles helvola, Monarda fistulosa, Aquilegia canadensis,* and *Vitis vulpina.* Somewhat farther toward the south *Juglans nigra* appears near the base of the hill not far above water-level; farther along it extends higher and even appears at the top of the dune. *Cercis canadensis* is usually found with it. In the same way the river birch, *Betula nigra,* the elm, *Ulmus americana,* the green ash, *Fraxinus pennsylvanica,* var. *lanceolata,* and finally the soft maple, *Acer saccharinum,* appear first at the bottom of the dune and as mesophytic conditions increase toward the southward extend higher and higher above water-level, until they finally appear at the top. Each one of these species is more moisture-loving than its predecessors, until the climax is reached in the soft maple, a characteristic tree of river-bottom swamps, here growing many feet above the water.

The change in the herbaceous and shrubby flora and ground cover is no less manifest. *Cornus Baileyi* and *Scrophularia leporella* soon appear; *Celastrus scandens* becomes a common liane; and *Zanthoxylum americanum* grows high above the river. Following these, dense mats of moss and *Peltigera* cover the sand and aid in the increase and conservation of soil moisture. With them come such pronounced mesophytes as *Parietaria pennsylvanica, Aster oblongifolius, Anychia canadensis,* and finally *Woodsia obtusa* and *Anemone canadensis.* The last species, together with the soft maple, is sufficient proof of the extraordinary change that has taken place in the water factor. Bare sand is seldom exposed, but is covered with the dense mats of moss and *Peltigera,* and shaded by the luxuriant tangle of herbaceous plants and shrubs. The few bare spots are still occupied with the typical black oak vegetation of *Artemisia caudata, Rudbeckia hirta,* and other similar species.

The further fate of this association will be described later in connection with the vegetational history of the river dune as a physiographic form.

In the Hanover area, the conditions which lead to succession are virtually the same as in the Havana area, but a much smaller area has been affected. *Psedera quinquefolia* is one of the pioneers, as usual, and is followed by a considerable number of species of mesophytic character. Among these are the following.

Trees:

Betula nigra
Ulmus americana
Celtis occidentalis
Fraxinus pennsylvanica, var. *lanceolata*

Shrubs:

Ribes gracile
Rubus idaeus, var. *aculeatissimus*
Rubus occidentalis
Prunus virginiana
Rhus glabra
Ceanothus americanus
Cornus Baileyi

Lianes:

Smilax ecirrhata
Smilax herbacea
Menispermum canadense
Rhus Toxicodendron
Vitis vulpina

Herbs:

Polygonatum commutatum
Silene stellata
Amphicarpa Pitcheri
Ziza aurea

Aquilegia canadensis
Ranunculus abortivus
Heuchera hispida
Fragaria virginiana,
var. *illinoensis*
Geum canadense
Asclepias phytolaccoides
Apocynum androsaemifolium
Monarda mollis
Eupatorium serotinum
Eupatorium urticaefolium
Antennaria plantaginifolia

The River Dunes and their Plant Associations

In the preceding pages those various associations have been described which comprise most of the vegetation of the sand areas. The chief physical factors concerned in molding their topography or differentiating their associations have been wind and soil moisture. There remains to be discussed the narrow strip of dunes which lies close along the Mississippi river and which is affected also by water action. The river dunes are well developed in the Hanover and Oquawka areas along the Mississippi river, whose swift current and shifting channel have been chiefly responsible for their origin. They are much less prominent along the Illinois river, whose sluggish current possesses but little power of erosion. The first stages in the vegetational history of the dunes were observed only in the Hanover area; the last, from and including the development of the oak forest, only in the Oquawka area.

In the first two areas, the sand deposits lie at an average height of 15-30 feet (5-10 m.) above the swampy, alluvial flood-plain. The river meanders across its flood-plain from side to side, and in some places flows directly at the foot of a sand hill. Under these conditions a river dune may be formed. Erosion by the river carries away the sand from below, and that portion of the sand above the high-water mark of the river, and consequently removed from the direct erosive action, stands at a steep slope, the angle of which depends upon the wind, the rate of erosion, and the vegetative covering. The surface sand on this slope is exposed to the full sun and keeps loose and dry. Below ordinary high-water mark the sand is worked over by the water and lies at a gentle slope, forming a broad or narrow beach. The wind, which is generally from the west, removes sand from the lower slope, and to a less extent also from the steeper portion, carries it up the slope, and piles it in a long dune parallel with the river and several feet higher than the general level of the sand. As long as the river continues erosion on that part of its banks, the whole slope moves gradually back; if the wind constructs the dune as rapidly, or more rapidly, than the river erodes

it, the whole complex migrates slowly landward. If the river erodes more rapidly than the wind piles up the sand, the dune will soon be destroyed and only a bare slope remain. On the other hand, if the river shifts its channel, or for some other reason ceases erosion, the whole exposed surface will ultimately be fixed with vegetation and become static. From a physiographical standpoint, therefore, the whole dune consists typically of two divisions (Pl. XVII, Fig. 2): the lower, termed the middle slope, consists of sand now being uncovered and removed by the wind and erosion; and the upper, called the upper slope, of sand deposited by the wind, and removed by undermining through erosion. From the standpoint of vegetation, several associations may be distinguished which are in part correlated with the physiography.

The lowest portion of the dune, near the river and within reach of high water, is marked by vegetation of a semi-hydrophytic nature. When visited in June, 1908, the river was very high, and only the tops of the half-submerged plants could be seen. These were *Populus deltoides, Salix longifolia, Fraxinus pennsylvanica,* var. *lanceolata, Gleditsia triacanthos,* and *Ulmus americana,* typical sand-bar or river-bottom plants. The herbaceous vegetation of a later season is doubtless of the same ecological nature, probably including *Eupatorium serotinum, Xanthium commune,* and other species of similar habitat. This vegetation has no relation to the typical dune vegetation above it, except in the presence of a few individuals of *Panicum virgatum,* which had probably slid down from the slope above.

The vegetation of the middle slope clearly belongs to the blowsand association, as described under the blowout formation. The plant covering is sparse, becoming somewhat dense toward the bottom. It consists chiefly of *Cassia Chamaechrista* and *Diodia teres,* with smaller numbers of *Croton glandulosus,* var. *septentrionalis, Ambrosia psilostachya,* and *Cristatella Jamesii.* At wide intervals are tufts of perennials, including *Acerates viridiflora,* var. *lanceolata, Panicum virgatum, Lithospermum Gmelini, Euphorbia corollata, Cyperus Schweinitzii,* and *Tephrosia virginiana.* The surface of the sand is dotted with numerous pebbles, sometimes as much as 2 inches in diameter. They apparently do not affect the vegetation, and there are not enough of them to be called gravel. They evidently represent the accumulation of pebbles left by the sand blowing up into the deposits above.

The top of the middle slope is marked by the outcrop of a layer of loamy sand (Pl. XVII, Fig. 2), very dark brown in color, rather fine-grained, and conspicuously earthy in texture. The top of this layer is well marked, but it gradually passes below into the typical orange-

brown sand of the middle slope. It is caused by past generations of plants which occupied this surface before the dune was formed, or at least before it had migrated so far inland. Since this soil blows, weathers, or dries out less rapidly or easily than the pure sand, the outcrop is marked by a slightly steeper slope and by dark-colored patches. Digging behind shows that the stratum extends indefinitely beneath the sand. For long distances the outcrop line is very distinct, but not perfectly level. Its elevation varies gradually, but irregularly, and in some places the whole outcrop disappears, corresponding to irregularities in the original level of the sand, or to locations of former blowouts. This soil stratum is on the same level as the country behind the dune and illustrates plainly the continued inward migration of the dune. (Cf. also Pl. XVIII, Fig. 2.) It is characterized now by a line of *Elymus canadensis.*

The upper slope consists of fine sand piled at an average angle of about 20 degrees. The vegetation is much like that of the middle slope, but denser and with many additional species (Pl. XVII, Fig. 2). It is likewise referred to the blowsand association. *Cassia Chamaechrista* and *Diodia teres* are again the most abundant species, and *Aristida tuberculosa* is also conspicuous. Other less characteristic species are *Monarda punctata, Lithospermum Gmelini, Euphorbia corollata, Diodia teres, Cristatella Jamesii, Ambrosia psilostachya, Oenothera rhombipetala, Linaria canadensis, Kuhnia eupatoriodes,* var. *corymbulosa, Acerates viridiflora,* var. *lanceolata* and var. *linearis, Oxybaphus nyctagineus, Teucrium occidentale, Tradescantia reflexa, Lespedeza capitata,* and *Rumex Acetosella.* In somewhat sheltered places *Scrophularia leporella, Draba caroliniana,* and *Corydalis micrantha* occur.

In some places, near the top of the slope, adjacent to the thickets described later, are associations of *Physalis heterophylla* (Pl. XVIII, Fig. 1). The individual plants grow in large patches and are very loosely aggregated, with a large amount of open sand between them, yet the patches are remarkably free from other plants. Even *Cassia* and *Diodia,* so abundant on the upper slope, are almost entirely absent from these patches. This peculiarity of distribution leads to the inference that they are more closely related ecologically to the thickets which crown the dunes than to the slope below. They may bear the same relation to the blowsand association that *Smilacina stellata* on the lee slope bears to the deposit association.

The crest of the river dune is primarily an area of deposit, and is consequently occupied at first by the regular deposit association, already described in connection with the blowout formation. *Rhus*

canadensis, var. *illinoensis* is again the most important member of the association. The perpetuation and vertical growth of the river dune are chiefly due to its efficiency as a sand-binder. The general height of the dune thus held is from 15-30 feet (5-10 m.) above the general level of the sand, but a maximum height of about 80 feet (25 m.) is attained in the Oquawka area, or fully 100 feet (30 m.) above the high-water level of the river. It is noteworthy that this highest point is occupied by a loose patch of *Rhus*, evidently of great age. Associated with *Rhus* on these dunes are similar dense patches of *Ceanothus ovatus* and, occasionally, of *Rhus Toxicodendron*. This shrubby habit of the last species was not observed elsewhere in the region, but is very common along the dunes of Lake Michigan, particularly toward the north, and is reported from Lake Erie by Jennings (*1909*). There are also the usual bunches of *Tephrosia virginiana*, *Panicum virgatum* (Pl. XX, Fig. 1), and, more rarely, *Eragrostis trichodes* and *Sporobolus cryptandrus*. Intervening spaces of open sand are occupied by the usual members of the blowsand association.

If the erosion by the river proceeds at such a rate that the crest of the dunes remains relatively stable for some years, opportunity is given for the development of a higher type of vegetation. The first step in this succession depends upon the introduction of seeds by wind or animals from the alluvial bottom-lands. The species most frequently introduced in this way are *Ulmus americana* and *Fraxinus pennsylvanica*, var. *lanceolata*, both of which have light winged seeds. Pods of *Gleditsia triacanthos* are blown up the slope from the trees on the river bank below, and more rarely *Juglans nigra* develops from seeds probably carried by animals. Seeds of *Acer saccharinum* were also found on the dunes, but they probably do not germinate, since no young plants were seen. These trees are not numerous, and never reach a large size, partly because of the unfavorable habitat, but chiefly because of the general movement of the dune. All the older trees have portions of their root systems exposed. One ash tree, 8 inches (2 dm.) in diameter, had the base of its stem 3 feet (1 m.) above the surface and 15 feet (5 m.) behind the present crest of the dunes (Pl. XVIII, Fig. 2). The ash, which is by far the most abundant of the trees, usually branches freely from the base, forming a complex of stems.

The trees offer a roosting place for birds, which in turn serve as agents in the dispersal of several shrubs and lianes. These at once spring up beneath the trees, and develop the dune thicket association. The mature thickets (Pl. XIX, Fig. 1) are exceedingly dense, impenetrable tangles of shrubs and lianes, with an occasional tree, half

smothered with vines, rising above them. Eight species of shrubs or small trees and seven species of lianes are concerned and, with a single exception, all have seeds adapted to dispersal by birds. They are as follows:

Smilax herbacea
Smilax hispida
Salix longifolia
Celtis occidentalis
Menispermum canadense
Ribes gracile
Pyrus ioensis
Prunus virginiana
Prunus serotina
Prunus sp. (plum)
Rhus Toxicodendron
Celastrus scandens
Psedera quinquefolia
Vitis vulpina
Cornus Baileyi

The choke-cherry (*P. virginiana*), plum, and crab (*Pyrus ioensis*) are the most abundant shrubs. The plum has running roots which send out shoots at short intervals, so that it tends to spread out upon the blowsand. The lianes are usually luxuriant and cover the shrubs with such masses that the supports are almost hidden. Within the thicket the light is very low; many of the branches are leafless or dead, and the herbaceous vegetation is scanty. It consists of *Teucrium occidentale, Scrophularia leporella, Polygonatum commutatum,* and *Smilacina racemosa,* with seedlings of *Psedera quinquefolia.* These thickets occupy the crest of the dunes and usually extend also some distance down the lee side. In some places the advance of the dune is sufficiently rapid to bring a portion of the thickets over to the windward side, where they are soon undermined (Pl. XIX, Fig. 2).

The further fate of these thickets is not known. It is worthy of note that they are somewhat similar in floristic composition to the thickets developing in certain blowouts, as described elsewhere in this paper (p. 107) and also in an earlier article (Hart and Gleason, *1907:* 168). Many of the species concerned are also characteristic of the mixed forest association and indicate a possible succession in that direction.

Just at the margin of the thickets on the lee side, and partially shaded by them, patches of *Smilacina stellata* frequently occur. The plant spreads by running rootstocks, but is not efficient as a sand-binder. The few patches on the windward side of the thickets are very soon undermined and destroyed. This small association encroaches upon the deposit association in advance of the thickets, and is dependent upon the thickets for a partial protection from sunlight. It illustrates a peculiar case of succession in which an early stage is dependent upon a later stage for its existence and appears only after

the later stage (in this case the dune thicket association) is well developed.

Blowouts may be formed on the crest of the river dune in the usual way, and extend transversely through it. They seldom reach below the old soil bed which marks the limits of the middle slope. Their vegetation is of the usual type, except that the lateral slopes are frequently held by the plums and crabs of the thicket association.

In some places in the Hanover area the river dune is occupied by the black oak association. The erosion there is generally feeble and the dune relatively stable. It seems probable that the oaks would also develop on the dunes stabilized by the ordinary deposit association if the thickets did not encroach upon them so rapidly. *Smilacina stellata,* as already mentioned, is a characteristic member of the black oak association, and its position on the dunes between the thicket and the deposit associations possibly indicates a potential development of the black oak forest at this place.

In the Oquawka area the greater portion of the river dune is forested, and in parts of it the development of humus and the increased density of the ground cover has led to the establishment of a mesophytic type of forest, described already (p. 137) under the mixed forest association. This portion of the dune is no longer washed by the river itself, but by some sluggish bayous representing a former channel of the river and separated from the present channel by a number of densely wooded alluvial islands. At the foot of these islands the channel bends eastward against the foot of the dune and erosion is now proceeding rapidly. The plant covering is an efficient protection against wind erosion, and the dune would be completely stable if it was farther inland, but it can not resist the undermining effect of the water. On a strip several hundred yards long the forest has been completely destroyed (Pl. XX, Fig. 1), and the vegetation now consists entirely of the blowsand and deposit associations. At the north end of the deforested portion the destruction of the forest is still proceeding. The effect of the erosion is first manifested at the foot of the dune, and its influence gradually extends higher until eventually the trees at the top are undermined. There is thus produced a triangular extension of the blowsand, extending like a wedge along the river between the water below and the forest above. It is now seen that the principal root development of the herbaceous vegetation extends but one or two feet (3-5 dm.) below the surface, and binds the sand into a coherent stratum resting on the loose sand beneath (Pl. XX, Fig. 2). The loose sand rests at as steep an angle as possible, and irregular blocks of the surface layer become detached

and slide slowly down the incline toward the river. Their sides are nearly vertical, and by their detachment the margin of the remaining forest association is left as a prominent vertical wall of coherent sand. The motion of these detached blocks is of course very slow; but that they are loose is at once demonstrated by stepping on one, which then immediately starts down the slope and in a short time comes to rest on the flat beach at the base of the dune. Their plant population is a relic of the former mesophytic vegetation, and consists largely of perennials with a root system extensive enough to bind the mass together. Some of the commoner species are *Lespedeza capitata, Tradescantia reflexa, Monarda mollis, Solidago nemoralis,* and *Artemisia caudata.* The more pronounced mesophytes of course disappear with the removal of the protecting trees.

The general trend of vegetation on the river dunes is therefore always toward stabilization, but their permanence is never certain because of the constant changes in the channel of the river. With the destruction of the higher types of vegetation by erosion, the pioneer blowsand association reappears and the successional cycle begins anew.

The Perched Dunes

In the Hanover area wind-blown sand has collected on top of the high bluffs which border the sand areas, and forms miniature dunes and blowouts. A number of typical sand plants have colonized upon them, and are usually accompanied by the more resistant species of the uplands or of the rocky hillsides. In the blowouts, which are always small, the vegetation represents the blowsand association and consists of *Scutellaria parvula, Linaria canadensis, Monarda punctata, Verbena bracteosa, Ambrosia psilostachya, Festuca octoflora,* and *Hedeoma hispida.* On the stabilized dunes there are also *Opuntia Rafinesquii, Artemisia caudata, Amorpha canescens, Lithospermum Gmelini, Rhus canadensis,* var. *illinoensis, Panicum pseudopubescens, Viola pedata,* and *Lespedeza capitata.* In the sandy soil under the oaks are *Cacalia atriplicifolia, Hypoxis hirsuta, Lithospermum Gmelini, Phlox pilosa, Antennaria* sp., *Anemone patens,* var. *Wolfgangiana, Erigeron pulchellus, Poa pratensis, Corylus americana,* and *Juniperus virginiana.*

Annotated List of Species

No attempt was made to secure a complete collection or a complete list of the plants living in the sand regions, and the list given

here could be greatly extended by further observation. Only the seed-plants, ferns, and fern-allies are included, and the usual habitat of each species is given by associations. Many unusual locations of species are omitted. The nomenclature follows the Vienna Code, as exemplified in the seventh edition of Gray's Manual.

Polypodiaceae

Pteris aquilina L. Winnebago, Amboy, and Havana areas, in the black oak association; Kankakee area, very abundant in the black oak forest and the intervening marshy meadows; sometimes persisting as a relic in the bur oak association in the Winnebago area.

Woodsia obtusa (Spreng.) Torr. Oquawka area, in the mixed forest association, growing in dense shade on mats of moss on the mesophytic portions of the river dune. Not observed elsewhere in the sand region.

Ophioglossaceae

Botrychium ternatum (Thunb.) Sw., var. *intermedium* D. C. Eaton. Winnebago area, in the upland portions of the bur oak association.

Botrychium virginianum (L.) Sw. With the last species.

Equisetaceae

Equisetum arvense L. Dixon area, in the *Solidago* association in extinct blowouts.

Equisetum hyemale L. Oquawka area, an invader from the alluvial flood-plain vegetation into the mixed forest association on the river dune.

Equisetum hyemale L., var. *intermedium* A. A. Eaton. Hanover, Dixon, and Havana areas, usually in the bunch-grass association; sometimes growing in dense masses and aiding in the stabilization of blowout deposits; abundant in the *Solidago* association in the Havana area.

Selaginellaceae

Selaginella rupestris (L.) Spring. Hanover area, in the bunch-grass association. It is frequently concerned in the fixation of sand and the re-establishment of the bunch-grass, and sometimes appears in the windward slope association of the blowouts. The growth rings formed by this plant have been described in the text.

Pinaceae

Juniperus virginiana L. Hanover area, frequent on the rocky exposed bluffs and from them invading the perched dunes.

Gramineae

Andropogon scoparius Michx. One of the most typical sand grasses in the Hanover, Amboy, Dixon, Oquawka, and Havana areas; very frequent in the bunch-grass association and persisting from it as a relic in the *Panicum pseudopubescens* and the black oak associations.

Andropogon furcatus Muhl. An abundant and important grass, but by no means as common as the preceding species. Hanover, Amboy, Dixon, Oquawka, and Havana areas, normally in the bunch-grass association, but persisting as a relic in the black oak and *Solidago* associations, and sometimes appearing on blowout deposits.

Sorghastrum nutans (L.) Nash. Hanover, Amboy, Oquawka, and Havana areas, in the bunch-grass association, and as a relic in the edge of the black oak association.

Digitaria filiformis (L.) Koeler. Hanover, Oquawka, and Havana areas, apparently not native, but coming in as a weed along roadsides or in too closely cropped pastures.

Leptoloma cognatum (Schultes) Chase. Abundant in each area except Winnebago and Kankakee, chiefly in the bunch-grass, where it may be dominant, also as a relic in the edge of the black oak association, in the *Panicum pseudopubescens* association, and on the windward slope of blowouts; it also appears early on blowout deposits.

Paspalum setaceum Michx. Hanover, Dixon, Oquawka, and Havana areas, typically in the blowsand association, and continuing on the deposits, also as an interstititial in the bunch-grass and in bare spots at the edge of the black oak association.

Panicum pseudopubescens Nash. Abundant in each of the five areas in a variety of situations; common in the bunch-grass association but usually as a secondary species; characteristic of the association to which it gives its name; persisting as a relic in the blowout succession in the windward slope and deposit associations; frequent in open sunny places in the black oak forest; rare in the blowsand association; and, in the Dixon area, depauperate plants persist in the mats of *Polytrichum*.

Panicum virgatum L. Common throughout but not abundant, usually in the bunch-grass association, but in the Hanover area one of the commonest dune-formers on the blowout deposits or the crest

of the river dunes; rare in open places in the black oak association, or as a relic in other situations.

Panicum perlongum Nash. Hanover, Havana, and Winnebago areas, common in the bunch-grass and *Panicum pseudopubescens* associations, or in open places in the black oak association.

Panicum Scribnerianum Nash. Only in the most mesophytic stations of the bunch-grass association in the Havana, Hanover, Dixon, and Oquawka areas; along roadsides and at the edge of the black oak forest in the Amboy and Winnebago areas.

Setaria glauca (L.) Beauv. Naturalized from Europe. Hanover area, a weed in pastured bunch-grass.

Cenchrus carolinianus Walt. Hanover, Dixon, Havana, and Oquawka areas; regularly in the blowsand association or as an interstitial on blowout deposits.

Stipa spartea Trin. In the bunch-grass association in the Hanover, Dixon, Havana, and Oquawka areas, more rarely on deposits or at the edge of black oak woods; also in a pastured field in the Winnebago area.

Aristida basiramea Engelm. Oquawka area, according to Patterson.

Aristida tuberculosa Nutt. Hanover, Dixon, Havana, and Oquawka areas, common as an interstitial in the bunch-grass and *Panicum pseudopubescens* associations, very abundant and characteristic in the blowsand association, common at the edge of the black oak forest, and in the Dixon area abundant in the *Solidago* association.

Sporobolus cryptandrus (Torr.) Gray. Chiefly in the blowsand and deposit associations of the Hanover, Havana, and Oquawka areas, sometimes in bare sunny spots in the black oak forest.

Sporobolus heterolepis Gray. Oquawka area, according to Patterson.

Calamovilfa longifolia (Hook.) Hack. Dixon, Havana, and Oquawka areas, in the bunch-grass association or persisting as a relic in open places in the black oak association.

Koeleria cristata (L.) Pers. Hanover, Winnebago, Dixon, and Oquawka areas, abundant and conspicuous in the bunch-grass; persisting as a relic in the black oak and *Panicum pseudopubescens* associations; and in rare cases appearing on blowout deposits.

Spartina Michauxiana Hitchc. Amboy area, along roadsides, doubtless adventive from the swampy meadows below.

Bouteloua hirsuta Lag. Hanover, Havana, and Oquawka areas, common but inconspicuous in the bunch-grass, where it grows as an

interstitial between the larger grasses, rarely persisting in the *Panicum pseudopubescens* and black oak associations.

Bouteloua oligostachya (Nutt.) Torr. Hanover area, according to Pepoon.

Bouteloua curtipendula (Michx.) Torr. Havana and Oquawka areas, in the bunch-grass association.

Tridens flavus (L.) Hitchc. Havana area, chiefly in the bunch-grass, but also in the black oak association and rarely as a relic in the *Panicum pseudopubescens* association.

Triplasis purpurea (Walt.) Chapm. Oquawka area, in the blowsand association, according to Patterson.

Eragrostis trichodes (Nutt.) Nash. Havana and Oquawka areas, typically in the bunch-grass but also in the black oak and deposit associations.

Eragrostis pectinacea (Michx.) Steud. Hanover, Havana, and Oquawka areas, always in the bunch-grass association.

Poa compressa L. Sunny places in the black oak association, Havana area.

Poa pratensis L. In a large variety of situations in each area, but chiefly where the land has been pastured or along roadsides.

Festuca octoflora Walt. Hanover, Winnebago, and Oquawka areas, chiefly as an interstitial in the bunch-grass, but also common in the blowsand association.

Hordeum pusillum Nutt. A weed along the roadsides in the Oquawka area.

Elymus virginicus L. Oquawka area, occasional in the bunch-grass association.

Elymus canadensis L. Hanover and Oquawka areas, in the bunch-grass association and sometimes as a relic in the *Panicum pseudopubescens* association.

Elymus striatus Willd. Oquawka area, a typically mesophytic species of the mixed forest association on the river dune.

Cyperaceae

Cyperus rivularis Kunth. Havana area, in the swamp association of an extinct blowout.

Cyperus Schweinitzii Torr. Hanover, Dixon, Havana, and Oquawka areas, chiefly in the bunch-grass; common also in the *Panicum pseudopubescens* association and rarely in the blowsand.

Cyperus filiculmis Vahl. Hanover, Winnebago, Havana, and Oquawka areas, a common interstitial of the bunch-grass, frequent

in the blowsand and *Panicum pseudopubescens* associations, and more rarely in open places in the black oak woods.

Eleocharis obtusa (Willd.) Schultes. In the swamp association in the Dixon and Havana areas.

Stenophyllus capillaris (L.) Britton. The characteristic species of the *Stenophyllus* association in the bottoms of partially stabilized blowouts in the Hanover, Havana, and Oquawka areas, rarely in the *Solidago* and bunch-grass associations.

Scirpus validus Vahl. Around the margin of a pond in a depression between the dunes, Winnebago area.

Scirpus cyperinus (L.) Kunth. Common in the swamp association and occasional in the *Salix* association in the Dixon area.

Carex festucacea Schkuhr, var. *brevior* (Dewey) Fernald. An interstitial in the bunch-grass association in the Hanover and Oquawka areas; not common.

Carex Muhlenbergii Schkuhr. Abundant in the bunch-grass association in the Hanover, Havana, Dixon, and Oquawka areas, and sometimes becoming the dominant species; one of the commoner bunch-grass relics in the *Panicum pseudopubescens* association; infrequent on the deposits and windward slopes of blowouts; in the black oak association in the Hanover, Winnebago, Havana, and Oquawka areas.

Carex umbellata Schkuhr. Hanover, Havana, and Dixon areas, most abundant in the *Panicum pseudopubescens* association, persisting as a relic on the windward slopes, occasional in the bunch-grass association, and rare on the deposits of blowouts.

Carex pennsylvanica Lam. Oquawka area, in the bunch-grass association; Winnebago area, in open places in the black oak association.

Carex sp. Dixon area, in the Solidago association.

Commelinaceae

Commelina virginica L. Havana and Oquawka areas; one of the most abundant interstitial species, growing in a wide variety of associations, but probably most abundant on blowout deposits.

Tradescantia reflexa Raf. Hanover, Kankakee, Winnebago, Amboy, Havana, and Oquawka areas; common in the bunch-grass and black oak associations and persisting as a relic in the bur oak and *Panicum pseudopubescens* associations.

Juncaceae

Juncus tenuis Willd. Havana area, in the *Solidago* association; Winnebago area, in open places in the black oak association.

Juncus nodosus L. Dixon area, in the swamp association.

Juncus acuminatus Michx. Dixon and Havana areas, in the *Solidago* association, and also less frequently in the *Polytrichum* and *Salix* associations.

Liliaceae

Lilium philadelphicum L., var., *andinum* (Nutt.) Ker. Winnebago area, in the bur oak association.

Asparagus officinalis L. Havana area, in the mixed forest association.

Smilacina racemosa (L.) Desf. Hanover area, in the dune thicket association; Winnebago area, in the bur oak association; Havana area, in the mixed forest association, and occasionally in the black oak association.

Smilacina stellata (L.) Desf. Hanover, Winnebago, Amboy, and Havana areas, characteristic of the black oak association, and in the last area rarely also in the mixed forest association.

Polygonatum commutatum (R. & S.) Dietr. Hanover, Winnebago, Amboy, Oquawka, and Havana areas, characteristic of the bur oak and mixed forest associations, one of the earliest pioneers in the black oak forest, indicating the succession, and occasional in the blowout and dune thickets.

Smilax herbacea L. Hanover, Winnebago, Amboy, and Havana areas, chiefly in the bur oak and mixed forest associations, occasional as a pioneer in the black oak association, and in the Hanover area in the dune thickets.

Smilax cirrhata (Engelm.) Wats. Hanover, Winnebago, and Amboy areas, in the bur oak association, or as a pioneer in the black oak forest.

Smilax hispida Muhl. In the dune thickets in the Hanover area, mixed forest in the Oquawka area, and in the black oak and bur oak forest in the Amboy area.

Dioscoreaceae

Dioscorea villosa L. Havana area, in the mixed forest association.

Amaryllidaceae

Hypoxis hirsuta (L.) Coville. Hanover area, under oaks on the perched dunes.

Iridaceae

Sisyrinchium sp. Hanover and Oquawka areas, in the bunch-grass association and persisting as a relic in the *Panicum pseudopubescens* association.

Orchidaceae

Cypripedium parviflorum Salisb., var. *pubescens* (Willd.) Knight. Winnebago area, in the bur oak association.

Spiranthes cernua (L.) Richard. Dixon area, in the *Polytrichum* association.

Salicaceae

Salix nigra Marsh. Dixon area, in the *Salix* association.

Salix longifolia Muhl. Dixon and Havana areas, in the *Salix* association; Hanover area, in the dune thickets.

Salix pedicellaris Pursh. Dixon area, in the *Polytrichum* association.

Salix tristis Ait. Winnebago and Amboy areas, in the black oak association and as a relic in the bur oak forests; Havana area, in the mixed forest association.

Populus alba L. Oquawka area, frequently planted and escaped along roadsides and fence-rows.

Populus tremuloides Michx. Winnebago, Amboy, and Kankakee areas, in the swamps and meadows between the sand hills, and occasional in the bur oak association.

Populus grandidentata Michx. Amboy area, in the bur oak association, or occasionally as a pioneer in the black oak woods.

Populus deltoides Marsh. Hanover area, in the dune thickets; Dixon area, in the *Salix* association; Oquawka and Havana areas, in blowout thickets.

Juglandaceae

Juglans nigra L. Hanover area, in the dune thickets; Oquawka area, in the mixed forest association on the river dune.

Carya ovata (Mill.) K. Koch. Winnebago area, in the bur oak association.

Carya cordiformis (Wang.) K. Koch. Hanover area, in the mixed forest; Oquawka and Havana areas, in the black oak association and persisting in the mixed forest.

Betulaceae

Corylus americana Walt. Hanover area, on the perched dunes; Winnebago and Amboy areas, common in the bur oak association and occasional as a pioneer in the black oak forest.

Betula nigra L. Hanover and Oquawka areas, in the mixed forest association near the river.

Betula alba L., var. *papyrifera* (Marsh.) Spach. Hanover area, on the perched dunes.

Fagaceae

Quercus alba L. Winnebago area, in the bur oak association.

Quercus macrocarpa Michx. Winnebago and Amboy areas, the characteristic species of the bur oak association.

Quercus rubra L. Oquawka area, in the mixed forest association.

Quercus velutina Lam. Hanover, Winnebago, Amboy, Kankakee, Havana, and Oquawka areas, the characteristic species of the black oak association, persisting commonly as a relic in the mixed forest association and less commonly in the bur oak forest; common on the perched dunes in the Hanover area.

Quercus marilandica Muench. Havana and Oquawka areas, abundant in the black oak association, and persisting in the mixed forest.

Urticaceae

Ulmus americana L. Hanover and Oquawka areas, in the mixed forest association and in the dune thickets.

Celtis occidentalis L. Hanover and Havana areas, in the mixed forest association, and in the blowout and dune thickets.

Morus rubra L. Havana area, in the mixed forest association.

Boehmeria cylindrica (L.) Sw. Havana area, in the *Salix* association.

Parietaria pennsylvanica Muhl. Oquawka area, in the mixed forest association.

Santalaceae

Comandra umbellata (L.) Nutt. Hanover, Winnebago, Amboy, Oquawka, and Hanover areas, in the black oak association, or occasionally along roadsides.

Polygonaceae

Rumex altissimus Wood. Hanover area, in the black oak association.

Rumex Acetosella L. Hanover, Winnebago, Dixon, and Oquawka areas, a common interstitial in the bunch-grass association, and in cultivated ground, less frequently in the *Panicum pseudopubescens* association.

Rumex sp. Hanover area, in the blowsand association.

Polygonum aviculare L. Oquawka area, a weed along roadsides and in yards.

Polygonum erectum L. Oquawka area, a common roadside weed.

Polygonum tenue Michx. Hanover, Oquawka, and Havana areas, a common interstitial in the bunch-grass association and less commonly also in the *Panicum pseudopubescens* association.

Polygonella articulata (L.) Meisn. Hanover and Dixon areas, in the blowsand association; Hanover and Oquawka areas, in open places in the black oak association.

Chenopodiaceae

Cycloloma atriplicifolium (Spreng.) Coult. Havana and Oquawka areas, in the blowsand and deposit associations.

Chenopodium album L. Hanover, Havana, and Oquawka areas, common as a weed, occasional in the bunch-grass association and in open places in the black oak forest.

Amaranthaceae

Froelichia floridana (Nutt.) Moq. Dixon, Oquawka, and Havana areas, usually in the blowsand association, occasionally an interstitial in the bunch-grass association or open blowout deposits; Hanover area, along the railroad track, appearing as if introduced.

Phytolaccaceae

Phytolacca decandra L. Oquawka area, in waste places under the shade of trees.

Nyctaginaceae

Oxybaphus nyctagineus (Michx.) Sweet. Hanover, Dixon, and Oquawka areas, in the blowsand and blowout thicket associations, an interstitial in the bunch-grass, and frequent as a weed in waste places and along roads.

Illecebraceae

Anychia polygonoides Raf. Hanover, Havana, and Oquawka areas, in the black oak association.

Anychia canadensis (L.) BSP. Oquawka area, in the mixed forest association.

Aizoaceae

Mollugo verticillata L. Hanover, Dixon, Oquawka, and Havana areas, especially common in the blowsand association and occasional as an interstitial in the bunch-grass and *Panicum pseudopubescens* associations.

Caryophyllaceae

Arenaria lateriflora L. Winnebago area, in the bur oak association.

Silene antirrhina L. Hanover, Winnebago, Dixon, Havana, and Oquawka areas, an abundant weed in fields and a common interstitial in the bunch-grass and *Panicum pseudopubescens* associations.

Silene stellata (L.) Ait. f. Hanover, Winnebago, Havana, and Oquawka areas, characteristic of the bur oak and mixed forest associations and a pioneer in the black oak association.

Saponaria officinalis L. Hanover area, in the black oak association near dwellings.

Portulacaceae

Talinum rugospermum Holzinger. Winnebago, Oquawka, and Havana areas, in the black oak association; Hanover area, in the bunch-grass association.

Ranunculaceae

Ranunculus abortivus L. Hanover area, in the mixed forest association.

Anemone patens L., var. *Wolfgangiana* (Bess.) Koch. Hanover area, on the perched dunes.

Anemone caroliniana Walt. Hanover area, in the bunch-grass association.

Anemone cylindrica Gray. Hanover and Oquawka areas, in the bunch-grass and black oak associations; Winnebago and Amboy areas, in the black oak association.

Anemone virginiana L. Havana area, in the mixed forest association and appearing as a pioneer in the black oak association.

Anemone canadensis L. Oquawka area, in the mixed forest association.

Aquilegia canadensis L. Hanover and Oquawka areas, in the mixed forest association.

Delphinium Penardi Huth. Oquawka area, in the bunch-grass association.

Menispermaceae

Menispermum canadense L. Hanover area, in the dune thicket and mixed forest associations; Havana area, in the blowout thicket association.

Fumariaceae

Corydalis micrantha (Engelm.) Gray. Hanover area, in the blowout association on the river dune.

Cruciferae

Draba caroliniana Walt. Hanover area, in the bunch-grass association, and in sheltered places in the blowsand association on the river dune.

Lesquerella argentea (Pursh) MacM. Havana area, in the bunch-grass association.

Lepidium virginicum L. Hanover, Winnebago, Dixon, Oquawka, and Havana areas, especially abundant in the *Panicum pseudopubescens* association, a common interstitial in the bunch-grass association, occasional in the blowsand association, and common in open places in the black oak association.

Erysimum parviflorum Nutt. Havana area, in the bunch-grass association.

Arabis lyrata L. Hanover, Winnebago, and Oquawka areas, most abundant as an interstitial in the bunch-grass and *Panicum pseudopubescens* associations in the Hanover area, also in open places in the black oak association.

Capparidaceae

Polanisia graveolens Raf. Hanover, Oquawka, and Havana areas, frequent in the blowsand association and in the black oak forest.

Cristatella Jamesii T. & G. Hanover and Havana areas, in the blowsand association.

Saxifragaceae

Heuchera hispida Pursh. Winnebago area, in the bur oak association; Hanover and Oquawka areas, in the mixed forest association.

Ribes gracile Michx. Hanover and Havana areas, in the mixed forest association, occasional in the dune thickets and the black oak forest, or along fence-rows on the prairie.

Rosaceae

Spiraea salicifolia L. Dixon area, in the *Solidago* association.

Pyrus ioensis (Wood) Bailey. Hanover area, in the dune thickets.

Pyrus Malus L. Hanover area, in the blowout thicket association.

Pyrus americana (Marsh.) DC. Winnebago area, in the black oak association.

Fragaria virginiana Duchesne, var. *illinoensis* (Prince) Gray. Winnebago and Amboy areas, in the black oak association and as a relic in the bur oak association; Hanover area, in the mixed forest.

Fragaria vesca L., var. *americana* Porter. Winnebago area, in the bur oak association; Hanover area, on the perched dunes.

Potentilla arguta Pursh. Winnebago and Amboy areas, in the black oak association and along roadsides.

Potentilla argentea L. Winnebago area, in a pastured field.

Potentilla canadensis L. Winnebago area, in the black oak association.

Geum canadense Jacq. Hanover area, in the mixed forest association.

Rubus idaeus L., var. *aculeatissimus* (C. A. Mey.) Regel & Tiling. Hanover area, in the mixed forest association; Winnebago area, in the bur oak association.

Rubus occidentalis L. Hanover area, in the black oak and mixed forest associations and on the perched dunes; Winnebago area, in the black oak and bur oak associations.

Rubus sp. (Blackberry). Amboy area, in the bur oak association.

Agrimonia mollis (T. & G.) Britton. Winnebago and Amboy areas, in the bur oak association; Havana area, in the mixed forest association.

Rosa humilis Marsh. Hanover area, in the black oak and blowout thicket associations; Winnebago area, in the black oak forest and as a relic in the bur oak association; Dixon area, in the bunchgrass association.

Prunus serotina Ehrh. Hanover area, in the dune thickets; Winnebago area, in the bur oak association and as a pioneer in the black oak forest; Havana area, in the mixed forest association.

Prunus virginiana L. Hanover area, in the mixed forest and

dune thicket associations; Winnebago area, in the bur oak association; in both areas as a pioneer in the black oak association.

Prunus sp. (Plum). Hanover area, in the dune thickets.

Leguminosae

Gymnocladus dioica (L.) Koch. Havana area, in the mixed forest association.

Gleditsia triacanthos L. Hanover area, in the dune thicket association; Dixon area, planted on the deposits of a blowout; Oquawka area, along roadsides.

Cassia Chamaechrista L. Most abundant in the Havana and Oquawka areas, in the bunch-grass, blowsand, and black oak associations; Hanover area, in the blowsand association; Amboy area, in the black oak forest; Dixon area, in the *Solidago* association.

Cercis canadensis L. Oquawka area, in the mixed forest association.

Baptisia bracteata (Muhl.) Ell. Winnebago area, in the black oak association; Oquawka area, in the bunch-grass and *Panicum pseudopubescens* associations.

Lupinus perennis L. Winnebago and Amboy areas, in the black oak association; Kankakee area, in mucky meadows at the base of sand hills.

Trifolium pratense L. Oquawka area, roadsides.

Trifolium repens L. Oquawka area, along roadsides.

Amorpha canescens Pursh. Hanover, Winnebago, Amboy, Dixon, Kankakee, Oquawka, and Havana areas, most abundant in and typical of the bunch-grass association, persistent as a relic and common in the black oak association, and occasional in the bur oak and mixed forest associations; in the Hanover area, also on the perched dunes.

Petalostemum purpureum (Vent.) Rydb. Hanover and Oquawka areas, abundant in the bunch-grass; also in the black oak association in the Amboy and Oquawka areas; along roadsides in the Winnebago area.

Petalostemum candidum Michx. Hanover and Oquawka areas, in the bunch-grass association; Winnebago and Amboy areas, in the black oak association.

Tephrosia virginiana (L.) Pers. In all seven areas; abundant in the bunch-grass and black oak associations, frequent on blowout deposits, and occasional in the blowsand and *Panicum pseudopubescens* associations.

Robinia Pseudo-Acacia L. Oquawka area, commonly planted as

a sand-binder and escaping into the mixed forest and blowout thicket associations.

Desmodium grandiflorum (Walt.) DC. Winnebago area, in the bur oak association.

Desmodium illinoense Gray. Oquawka area, in the bunch-grass association; Amboy area, in the black oak forest.

Lespedeza capitata Michx. Common in all seven areas, chiefly in the bunch-grass and black oak associations; a relic in the *Panicum pseudopubescens* association, active in the stabilization of all parts of the blowouts; in the Dixon area it appears in the *Solidago* association; and in the Hanover area, on the perched dunes.

Strophostyles helvola (L.) Britton. Havana area, in the black oak forest; Oquawka area, in the bunch-grass, blowsand, black oak, and mixed forest associations.

Strophostyles sp. Havana area, in the bunch-grass association.

Amphicarpa Pitcheri T. & G. Hanover area, in the mixed forest association; Winnebago area, in the bur oak association.

Linaceae

Linum sulcatum Riddell. Hanover and Oquawka areas, in the bunch-grass association.

Oxalidaceae

Oxalis corniculata L. Hanover area, in the bunch-grass and black oak associations.

Geraniaceae

Geranium maculatum L. Winnebago area, in the bur oak association.

Rutaceae

Zanthoxylum americanum Mill. Oquawka area, in the mixed forest association.

Polygalaceae

Polygala polygama Walt. Hanover, Winnebago, Dixon, and Oquawka areas, in the bunch-grass, *Panicum pseudopubescens,* and black oak associations.

Polygala incarnata L. Oquawka area, in the bunch-grass association.

Polygala sanguinea L. Dixon area, in the *Solidago* association,

and as a relic also in the *Polytrichum* association; Amboy area, in muck meadows at the base of the dunes.

Polygala verticillata L. Hanover, Havana, and Oquawka areas, in the bunch-grass and *Panicum pseudopubescens* associations.

Euphorbiaceae

Croton glandulosus L., var. *septentrionalis* Muell. Arg. Hanover, Havana, and Oquawka areas, an interstitial in the bunch-grass and *Panicum pseudopubescens* associations, common in the blowsand association, and occasional on blowout deposits.

Crotonopsis linearis Michx. Havana area, a common interstitial in the bunch-grass, *Panicum pseudopubescens,* blowsand, deposit, and black oak associations.

Euphorbia Geyeri Engelm. Hanover, Dixon, Havana, and Oquawka areas, most abundant in the blowsand association, occasional as an interstitial in the bunch-grass and the black oak forest.

Euphorbia corollata L. Very abundant in all seven areas, chiefly in the bunch-grass and black oak association, frequent on blowout deposits, occasional in the blowsand association, and rare in the bur oak association.

Anacardiaceae

Rhus glabra L. Winnebago and Amboy areas, in the bur oak association; Hanover area, in the mixed forest association.

Rhus Toxicodendron L. Hanover, Oquawka, and Havana areas, in the mixed forest association, in the dune thickets, and occasionally a pioneer in the black oak forest; Winnebago area, in the bur oak and black oak associations.

Rhus canadensis Marsh., var. *illinoensis* (Greene) Fernald. Hanover, Havana, and Oquawka areas, in the bunch-grass, deposit, and black oak associations.

Celastraceae

Celastrus scandens L. Havana and Oquawka areas, in the mixed forest; Hanover area, in the dune thickets.

Aceraceae

Acer saccharinum L. Oquawka area, in the mixed forest association on the river dune.

Acer Negundo L. Havana area, in the blowout thicket association.

Rhamnaceae

Ceanothus americanus L. Hanover, Winnebago, Amboy, Oquawka, and Hanover areas, in the black oak, bur oak, and mixed forest associations; occasional in the bunch-grass in the Oquawka area.

Ceanothus ovatus Desf. Hanover area, in the bunch-grass, deposit, and black oak associations.

Vitaceae

Psedera quinquefolia (L.) Greene. Winnebago area, in the bur oak association; Hanover, Havana, and Oquawka areas, in the mixed forest, blowout thicket, and dune thicket associations, and one of the most frequent pioneers in the black oak association.

Vitis vulpina L. Winnebago and Amboy areas, in the bur oak association; Havana, Oquawka, and Hanover areas, in the mixed forest, the blowout thickets, and the dune thickets, and occasional as a pioneer in the black oak association.

Malvaceae

Callirhoe triangulata (Leavenw.) Gray. Hanover and Havana areas, chiefly in the bunch-grass and the black oak forests, and occasionally in the *Panicum pseudopubescens* association.

Hypericaceae

Hypericum cistifolium Lam. Oquawka area, in the mixed forest association along the river dune.

Hypericum mutilum L. Havana area, in the *Solidago* association.

Hypericum majus (Gray) Britton. In the *Polytrichum* association in the Dixon area.

Hypericum gentianoides (L.) BSP. Dixon area, in the *Polytrichum* association, or perhaps more common in a zone just outside of it.

Cistaceae

Helianthemum majus BSP. Hanover, Winnebago, Amboy, Dixon, Havana, and Oquawka areas, probably most widely distributed in the black oak association, but also abundant in the bunch-grass.

Hudsonia tomentosa Nutt. Hanover and Dixon areas, charac-

teristic of the *Hudsonia* association, and occasional upon blowout deposits and in black oak woods.

Lechea sp. In the black oak association in the Winnebago and Oquawka areas.

Violaceae

Viola pedata L. Hanover, Oquawka, and Winnebago areas, most abundant in the bunch-grass prairie and in the black oak woods, occasional in the *Panicum pseudopubescens* association and on blowout deposits.

Viola lanceolata L. Dixon area, in the *Polytrichum* association; Kankakee area, in the wet meadows.

Cactaceae

Opuntia Rafinesquii Engelm. Hanover, Oquawka, and Havana areas, usually very abundant in the bunch-grass and the open parts of the black oak forest.

Opuntia fragilis (Nutt.) Haw. Hanover area, in the bunch-grass and *Panicum pseudopubescens* associations.

Melastomaceae

Rhexia virginica L. Dixon area, in the *Polytrichum* and *Solidago* associations; Amboy area, in the wet meadows.

Onagraceae

Ludvigia alternifolia L. Havana area, in the *Salix* association.

Ludvigia palustris (L.) Ell. Dixon and Havana areas, in the swamp association, and persistent as a relic in the *Solidago* and *Polytrichum* associations.

Oenothera biennis L. In the bur oak association in the Winnebago area, and in the mixed forest in the Havana area.

Oenothera rhombipetala Nutt. One of the most common interstitials, occurring in all seven areas in a wide variety of associations, but most abundant in the bunch-grass and in the *Panicum pseudopubescens* association.

Circaea lutetiana L. In the bur oak forest in the Winnebago area.

Umbelliferae

Sanicula canadensis L. Winnebago and Havana areas, in the bur oak and mixed forest associations.

Zizia aurea (L.) Koch. Winnebago area, in the black oak forest; Hanover area, in the mixed forest.

Cornaceae

Cornus Baileyi Coult. & Evans. Hanover, Winnebago, Amboy, Havana, and Oquawka areas, in the bur oak and mixed forest associations; also in the dune thickets and the blowout thickets.

Ericaceae

Pyrola elliptica Nutt. In the bur oak association in the Winnebago area.

Monotropa uniflora L. Winnebago area, in the black oak forest, probably a pioneer from the bur oak association.

Primulaceae

Steironema lanceolatum (Walt.) Gray. Winnebago area, in the swamp association.

Dodecatheon Meadia L. Winnebago area, in the bur oak association.

Oleaceae

Fraxinus pennsylvanica Marsh., var. *lanceolata* (Borkh.) Sarg. Hanover and Oquawka areas, in the mixed forest and dune thicket associations and as a pioneer in the black oak forest.

Apocynaceae

Apocynum androsaemifolium L. Winnebago and Amboy areas, in the black oak forest and persisting as a relic in the bur oak association; Hanover area, in the mixed forest.

Apocynum cannabinum L., var. *hypericifolium* (Ait.) Gray. In blowsand in the Dixon area.

Asclepiadaceae

Asclepias tuberosa L. Hanover, Havana, and Amboy areas, in the black oak forest; Oquawka area, in the mixed forest; Winnebago area, along a sandy roadside.

Asclepias syriaca L. Hanover and Oquawka areas, near cultivated grounds around the river dune; Havana area, in the black oak and *Solidago* associations.

Asclepias amplexicaulis Sm. In the black oak forest in the Hanover, Winnebago, Amboy, Havana, and Oquawka areas; also in the bunch-grass association in the Dixon and Oquawka areas.

Asclepias phytolaccoides Pursh. Hanover and Havana areas, in the mixed forest association.

Asclepias verticillata L. In the black oak and bur oak forests in the Havana area, and along roadsides in the Hanover area.

Acerates floridana (Lam.) Hitchc. In the windward slope association in the Dixon area, probably a relic from the bunch-grass association.

Acerates viridiflora Ell. Hanover and Oquawka areas, in the bunch-grass and basin associations, and occasional in the *Panicum pseudopubescens* association; Winnebago area, in an open place in the black oak forest.

Acerates viridiflora Ell., var. *lanceolata* (Ives) Gray. Hanover and Havana areas, characteristic of the basin association, and occasional in the bunch-grass and *Panicum pseudopubescens* associations.

Acerates viridiflora Ell., var. *linearis* Gray. Hanover and Oquawka areas, in the basin and blowsand associations.

Convolvulaceae

Breweria Pickeringii (M. A. Curtis) Gray. In the bunch-grass prairies of the Oquawka area.

Ipomoea hederacea Jacq. A weed in cultivated fields in the Oquawka area.

Polemoniaceae

Phlox pilosa L. Perched dunes in the Hanover area.

Phlox bifida Beck. In the bunch-grass and black oak associations in the Havana and Winnebago areas.

Boraginaceae

Lappula virginiana (L.) Greene. Havana area, in the mixed forest association.

Lithospermum Gmelini (Michx.) Hitchc. Abundant in all seven areas, chiefly in the bunch-grass and black oak associations, more rarely in the basin, blowsand, and *Panicum pseudopubescens* associations.

Lithospermum angustifolium Michx. In the bunch-grass association in the Havana area.

Verbenaceae

Verbena stricta Vent. Havana, Oquawka, Dixon, and Hanover areas, occasional in the bunch-grass and black oak forest, and a weed along roadsides.

Verbena bracteosa Michx. Perched dunes and bunch-grass in the Hanover area.

Labiatae

Teucrium canadense L. Havana and Hanover areas, in the black oak and *Solidago* associations.

Teucrium occidentale Gray. Hanover area, an interstitial in the bunch-grass, and common in the blowsand association along the river dune.

Scutellaria parvula Michx. In the black oak association in the Hanover, Amboy, and Havana areas; also an interstitial in the bunch-grass in the Hanover area, and in the blowsand association in the Dixon area.

Nepeta Cataria L. Hanover area, in the black oak forest near dwellings.

Physostegia denticulata (Ait.) Britton. Oquawka, Havana, and Hanover areas, in the bunch-grass and black oak associations.

Leonurus Cardiaca L. Hanover area, near dwellings in the black oak forest.

Monarda fistulosa L. Oquawka area, in the black oak and mixed forest associations.

Monarda mollis L. Hanover, Winnebago, Amboy, Havana, and Oquawka areas, usually in the bur oak forest, but occasionally as a pioneer in the black oak association.

Monarda punctata L. Hanover, Dixon, Havana, Oquawka, and Kankakee areas, one of the most abundant interstitials in the bunch-grass, and common also in the *Panicum pseudopubescens* and blowsand associations and in open places in the black oak forest; very common as a weed in pastured ground.

Hedeoma hispida Pursh. Hanover, Dixon, and Oquawka areas, an interstitial in the bunch-grass, and common also in the *Panicum pseudopubescens* and blowsand associations.

Lycopus americanus Muhl. Havana area, in the *Salix* association; Dixon area, in the *Polytrichum* association; Amboy area, in the wet meadows.

Solanaceae

Solanum nigrum L. Hanover, Oquawka, and Havana areas, under the shade of trees.

Solanum carolinense L. Hanover and Oquawka areas, in the black oak forest and a weed in cultivated fields.

Physalis heterophylla Nees. Hanover, Winnebago, Dixon, and Havana areas, in the bunch-grass and black oak associations.

Physalis virginiana Mill. Hanover and Oquawka areas, in the black oak and bunch-grass associations.

Scrophulariaceae

Verbascum Thapsus L. Hanover, Winnebago, Oquawka, and Havana areas, usually in the black oak forest, but occasionally in the bunch-grass association.

Linaria canadensis (L.) Dumont. Hanover, Dixon, Oquawka, and Havana areas, a common interstitial in the bunch-grass, frequent in the *Panicum pseudopubescens* and blowsand associations, and occasional on blowout deposits.

Scrophularia leporella Bicknell. Hanover, Winnebago, Oquawka, and Havana areas, most abundant in the mixed forest and in the dune thickets, less frequent in the black oak forest.

Pentstemon hirsutus (L.) Willd. Hanover, Amboy, Havana, and Oquawka areas, common in the bunch-grass and the black oak forest, and occasional in the *Panicum pseudopubescens* and bur oak associations.

Pentstemon grandiflorus Nutt. In the bunch-grass and black oak associations of the Oquawka area.

Veronica virginica L. Winnebago and Amboy areas, in the bur oak association.

Synthyris Bullii (Eaton) Heller. Hanover, Winnebago, and Oquawka areas, characteristic of the black oak association and occasional as a relic in the bur oak forest, rare in the bunch-grass.

Gerardia grandiflora Benth. In the black oak association in the Winnebago and Amboy areas, and as a relic in the bur oak forest.

Gerardia purpurea L. In the *Solidago* association in the Dixon area.

Castilleja coccinea (L.) Spreng. Winnebago area, in the black oak association.

Pedicularis canadensis L. Winnebago area, in the black oak and bur oak associations.

Orobanchaceae

Orobanche fasciculata Nutt. Parasitic on *Artemisia caudata* in the bunch-grass association of the Hanover area.

Acanthaceae

Ruellia ciliosa Pursh. Havana and Oquawka areas, in the bunch-grass and black oak associations.

Plantaginaceae

Plantago Rugelii Dcne. Along roadsides in the Oquawka area.

Rubiaceae

Galium pilosum Ait. In the black oak forest in the Havana area.

Galium concinnum T. & G. Winnebago area, in the bur oak association; Havana area, in the mixed forest.

Diodia teres Walt. Hanover and Havana areas, common in the blowsand association, and occasional in the black oak forest and as a weed in cultivated ground.

Caprifoliaceae

Lonicera Sullivantii Gray. Winnebago area, in the bur oak association.

Campanulaceae

Specularia perfoliata (L.) A. DC. Hanover, Havana, and Winnebago areas, a common interstitial in the bunch-grass, occasional in open places in the black oak forest and one of the most abundant weeds in sandy fields.

Compositae

Vernonia fasciculata Michx. Havana area, in the *Solidago* association; Amboy area, in the wet meadows between the dunes; Hanover area, in pastured bunch-grass.

Eupatorium purpureum L. Havana area, in the mixed forest association; Amboy area, in the wet meadows at the base of the dunes.

Eupatorium serotinum Michx. Hanover area, in the black oak and mixed forest associations.

Eupatorium urticaefolium Reichard. In the mixed forest association in the Hanover and Havana areas.

Kuhnia eupatorioides L., var. *corymbulosa* T. & G. Hanover, Oquawka, and Havana areas, chiefly in the bunch-grass, but occasional in the blowsand and dune thicket associations.

Liatris cylindracea Michx. Hanover area, in the bunch-grass association; Winnebago and Amboy areas, in the black oak forest.

Liatris scariosa Willd. In the bunch-grass association in the Hanover, Dixon, Oquawka, and Havana areas; in the black oak forest in the Winnebago and Amboy areas.

Chrysopsis villosa Nutt. Hanover, Dixon, and Havana areas, common in the bunch-grass association; along roadsides in the Amboy area.

Solidago speciosa Nutt., var. *angustata* T. & G. Winnebago, Amboy, Hanover, and Havana areas, in the black oak forest; Hanover and Oquawka areas, in the bunch-grass association.

Solidago missouriensis Nutt. In the bunch-grass association in the Havana and Hanover areas.

Solidago nemoralis Ait. Abundant in all seven areas, in the black oak and bunch-grass associations; in the Hanover area, also in the *Panicum pseudopubescens* association.

Solidago serotina Ait. Hanover and Havana areas, in the black oak association.

Solidago rigida L. In the bunch-grass association in the Hanover area; along roadsides in the Amboy area.

Solidago graminifolia (L.) Salisb. Characteristic of the *Solidago* association in the Dixon and Havana areas; along sandy roadsides in the Amboy area; in a swamp between the dunes in the Winnebago area.

Aster oblongifolius Nutt. Oquawka area, in the mixed forest on the river dune.

Aster sericeus Vent. In the bunch-grass association in the Hanover, Havana, and Oquawka areas; in the black oak forest in the Hanover and Amboy areas; in the mixed forest on the river dune in the Oquawka area; in a cleared field in the Winnebago area.

Aster azureus Lindl. Winnebago, Amboy, Havana, and Oquawka areas, in the black oak association.

Aster multiflorus Ait. Havana, Oquawka, and Hanover areas, in the bunch-grass association.

Aster linariifolius L. Common in all seven areas in the bunch-grass and black oak associations, and occasionally persisting as a relic in the *Panicum pseudopubescens* association.

Aster sp. In the bunch-grass association in the Hanover area.

Aster sp. Dixon area, in the *Polytrichum* association.

Erigeron pulchellus Michx. On the perched dunes in the Hanover area.

Erigeron ramosus (Walt.) BSP. Hanover and Oquawka areas, in the bunch-grass and *Panicum pseudopubescens* associations; Winnebago area, in the black oak forest.

Erigeron canadensis L. An interstitial in the bunch-grass in the Hanover area, and on blowout deposits in the Oquawka area.

Antennaria plantaginifolia (L.) Richards. Hanover area, in the mixed forest association.

Antennaria sp. One or more unidentified species of *Antennaria* are common in the bunch-grass and black oak forests of the Hanover, Winnebago, Amboy, Dixon, Oquawka, and Havana areas.

Gnaphalium polycephalum Michx. Hanover area, in the bunch-grass; Amboy and Oquawka areas, in the black oak forest; in the latter area also in the *Stenophyllus* and blowout thicket associations.

Silphium laciniatum L. Along roadsides in the Amboy area.

Silphium integrifolium Michx. Amboy area, in the black oak forest.

Parthenium integrifolium L. Hanover area, in the mixed forest association; Amboy area, along sandy roadsides.

Ambrosia artemisiifolia L. A weed in the waste grounds in the Oquawka and Winnebago areas.

Ambrosia psilostachya DC. Observed in the Hanover, Winnebago, Dixon, Oquawka, and Havana areas, and probably in the others as well; a common interstitial in the bunch-grass, black oak, and *Panicum pseudopubescens* associations, and abundant in the blowsand association.

Xanthium commune Britton. A weed in sandy fields in the Oquawka area.

Rudbeckia hirta L. Hanover, Winnebago, Havana, and Oquawka areas, abundant in the black oak forest, and occasional in the mixed forest and bunch-grass.

Brauneria pallida (Nutt.) Britton. Hanover, Dixon, and Oquawka areas, in the bunch-grass association; Amboy area, along roadsides.

Lepachys pinnata (Vent.) T. & G. Winnebago area, in a clearing in the black oak forest.

Helianthus lenticularis Dougl. Oquawka area, in the blowsand association.

Helianthus scaberrimus Ell. Hanover and Oquawka areas, common in the bunch-grass and *Panicum pseudopubescens* associations; Amboy area, along sand roadsides.

Helianthus occidentalis Riddell. Common in all seven areas in the bunch-grass and black oak associations.

Helianthus occidentalis Riddell, var. *illinoensis* (Gleason) Gates. With the species, especially in more shaded places; occasional in the mixed forest association.

Helianthus strumosus L. Winnebago, Amboy, and Havana areas, in the black oak forest, and persisting as a relic in the bur oak and mixed forest associations.

Coreopsis palmata Nutt. Hanover, Winnebago, Amboy, and Oquawka areas, in the bunch-grass and black oak associations, rare as a relic in the bur oak forest; Havana area, in the mixed forest.

Hymenopappus carolinensis (Lam.) Porter. In the black oak association in the Kankakee area.

Achillea Millefolium L. Winnebago, Amboy, Dixon, and Oquawka areas, in the bunch-grass and black oak associations.

Anthemis Cotula L. A weed in the Oquawka area.

Artemisia caudata Michx. Very common in all seven areas in the bunch-grass and black oak associations, occasional as a relic in the *Panicum pseudopubescens* association.

Artemisia ludoviciana Nutt. Hanover area, occasional in the bunch-grass and black oak forest; more abundant in shaded places along fence-rows and thickets.

Cacalia atriplicifolia L. Hanover area, on the perched dunes; Winnebago area, in the bur oak forest; Havana area, in the black oak and mixed forest associations, and occasionally in the bunch-grass.

Senecio Balsamitae Muhl. Hanover and Oquawka areas, in the bunch-grass and black oak associations.

Krigia virginica (L.) Willd. Havana area, in the black oak association.

Krigia amplexicaulis Nutt. In the bur oak forest in the Winnebago area.

Lactuca scariola L., var. *integrata* Gren. & Godr. Oquawka area, in the *Stenophyllus* association.

Lactuca canadensis L. Hanover, Havana, and Oquawka areas, in the bunch-grass, occasional in the blowout thickets and the black oak forest.

Prenanthes alba L. Winnebago area, in the bur oak association, or as a pioneer in the black oak forest.

Hieracium longipilum Torr. In the black oak forest in the Winnebago area.

Hieracium canadense Michx. Hanover area, in the black oak association.

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October, 1910.

ERRATA

PLATE III, Fig. 1, after the word *mixed* in legend insert *consocies of the*.

PLATE IX, Fig. 2, dele the legend and read instead: Root-system of *Tephrosia virginiana*, exposed by blowing of the sand.

PLATE X, Fig. 2, dele the legend and read instead: A blowout almost stabilized by bunch-grasses, especially *Leptoloma cognatum*.

Plate I.

Fig. 1. General view of the sand-dunes near Havana. The isolated trees are *Quercus velutina*; at the right is a grove of *Juglans nigra*.

Fig. 2. *Leptoloma cognatum* consocies of the bunch-grass association, Oquawka area. Large bunches of *Andropogon scoparius* in the rear, and a flowering *Achillea Millefolium* in the center.

PLATE II.

Fig. 1. Mixed consocies of the bunch-grass association in the Hanover area, *Andropogon scoparius* most abundant.

Fig. 2. Mixed consocies of the bunch-grass association in the Hanover area. Various species of grasses and perennials in the foreground, and a society of *Ceanothus ovatus* behind.

Plate III.

Fig. 1. Luxuriant development of the mixed bunch-grass association in a depression between dunes in the Hanover area.

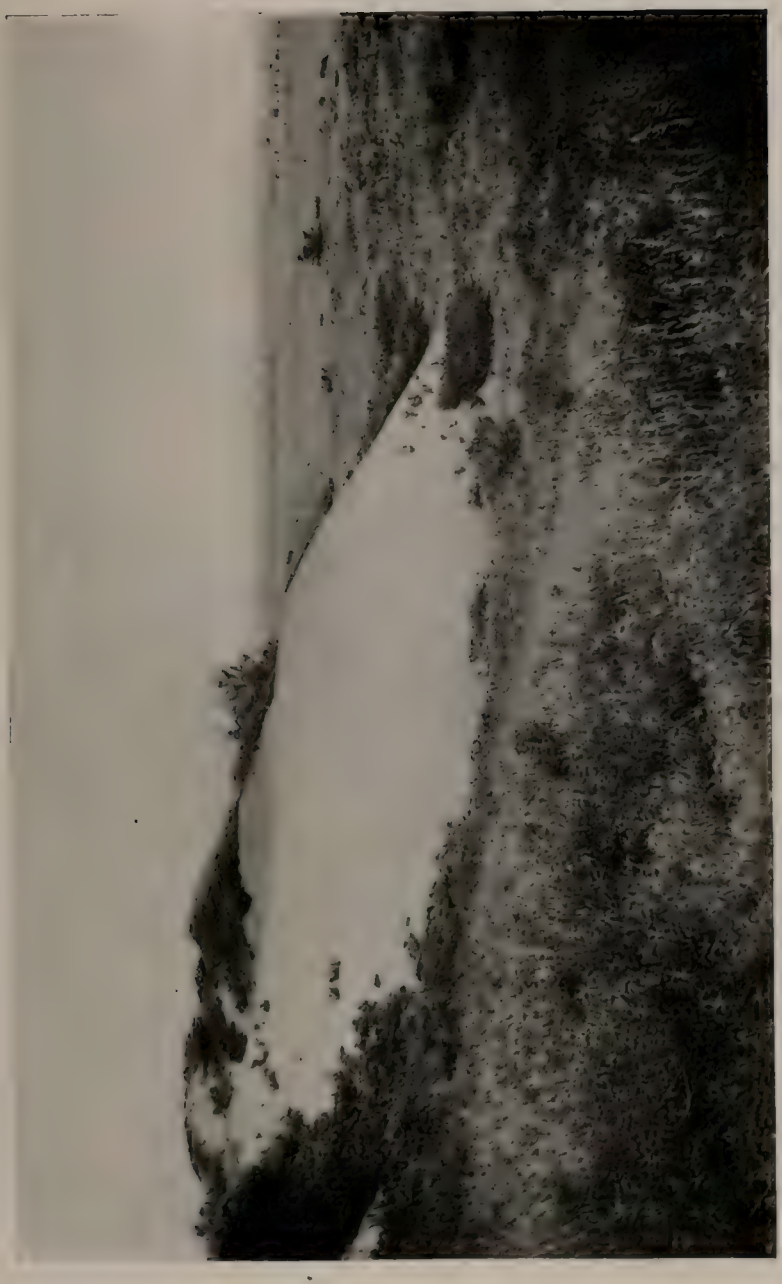
Fig. 2. Typical development of the *Panicum pseudopubescens* association, Hanover area.

PLATE IV.

Fig. 1. Typical blowout in the Hanover area, looking west. In the foreground, the deposit association, with *Panicum virgatum* dominant and many interstitials; behind this, the blowsand association, with *Diodia teres*; next, the basin, with a few plants of *Acerates*. The dunes at the side are held by *Rhus*.

Fig. 2. Blowout complex in the Hanover area, looking north. Bunches of *Panicum virgatum* are conspicuous. Typical habitat for *Cristatella Jamesii*.

PLATE V.



The deposits of the blowout shown in Plate VIII, Fig. 1. The bunch-grass association at the right.

PLATE VI.

Fig. 1. Young blowout in the Hanover area, looking north, indicating the differentiation of three associations. Detached bunches of *Panicum pseudopubescens* at the left, mark the windward slope; the deposits at the right are occupied with *Panicum virgatum*; while the basin has as yet no vegetation.

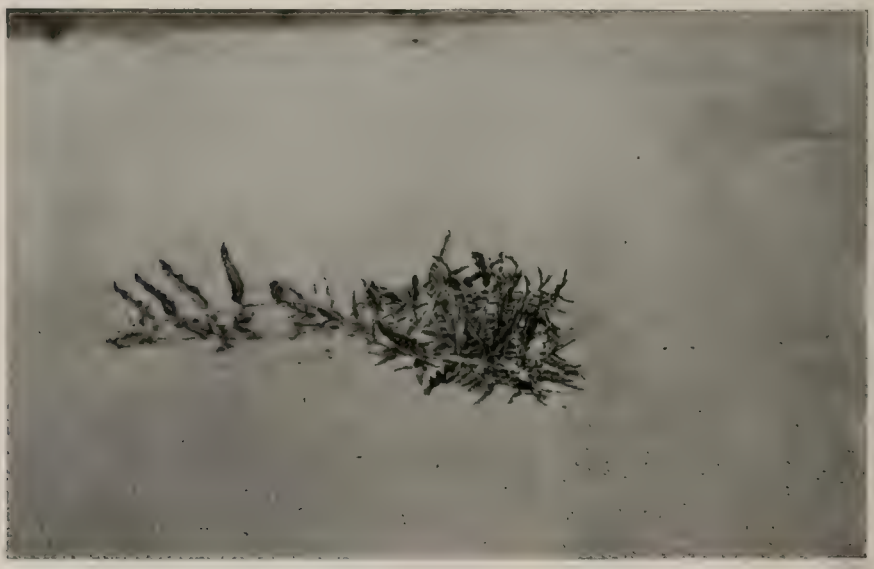


Fig. 2. *Acerates viridiflora*, var. *lanceolata*, in its typical habitat.

Plate VII.

Fig. 1. Incipient blowout on a hillside in the bunch-grass association, Hanover area. The windward slope is just developing in the background, while an extensive growth of *Panicum virgatum*, indicating the deposits, occupies the center. *Rhus* is in the foreground, at the right.

Fig. 2. Large blowout in the Hanover area, looking east. The dunes at the right are held by *Rhus*, *Tephrosia*, and *Panicum virgatum*, by *Tephrosia* alone at the left, and by *Tephrosia* and *Panicum* at the rear. The basin is almost bare.

Plate VIII.

Fig. 1. Large blowout in the river dune, Hanover area, looking east. The dunes at the left are held by *Rhus*; those at the right by *Prunus*, with various herbs in the blowsand association at their base. The basin is entirely bare.

Fig. 2. Seedlings of *Diodia teres* coming up in wagon tracks. Thickets of *Rhus* and bunches of *Panicum virgatum* at the rear.

Plate IX.

Fig. 1. Characteristic growth of *Tephrosia virginiana*.

Fig. 2. A blowout almost completely stabilized by bunch-grasses, especially *Leptoloma cognatum*.

Plate X.

Fig. 1. Extensive tract of blowsand in the Oquawka area near Keithsburg.

Fig. 2. Development of the *Stenophyllus* association in a shallow blowout, Hanover area. The conspicuous erect plants are *Oenothera rhombipetala*.

Plate XI.

Fig. 1. Development of the *Stenophyllus* association in a shallow blowout in the Hanover area. The conspicuous erect plants are *Oenothera rhombipetala*.

Fig. 2. Blowout in the Oquawka area. Stabilization is beginning, as shown by the persistence of the grasses at the base of the windward slope, the conspicuous plants of *Lespedeza capitata*, patches of moss, and by the thicket of *Populus deltoides* in the background, at the left.

Plate XII.

Fig. 1. Contact of the *Polytrichum* association with bare blowsand.

Fig. 2. Contact of the *Polytrichum* (see foreground) and bunch-grass associations.

Plate XIII.

Fig. 1. Pond "*E*," in a depression between dunes in the Dixon area, showing the zones of vegetation.

Fig. 2. Invasion of the bunch-grass by the black oak association, Hanover area.

PLATE XIV.

Fig. 1. Black oak association, Oquawka area. Typical habitat of *Synthyris Bullii*.

Fig. 2. Typical opening in the black oak association, Oquawka area, with *Tephrosia virginiana, Monarda punctata, Opuntia Rafinesquii*, etc.

Plate XV.

Fig. 1. Characteristic growth of *Pteris aquilina* near the margin of the black oak association, Winnebago area.

Fig. 2. Hillside in the Winnebago area, showing the transition from the black oak association on the upland (left) to the bur oak association in the lowland (right). The shrubbery is chiefly *Prunus virginiana*.

Plate XVI.

Fig. 1. Bur oak association, Winnebago area. *Rubus* sp. in the foreground, at the left; *Pteris aquilina* conspicuous under the trees.

Fig. 2. Black oak association, Oquawka area. A few young vines of *Psedera* and *Celastrus* have appeared, indicating the beginning of the succession to the mixed forest.

Plate XVII.

Fig. 1. Natural opening in the black oak association, Winnebago area, occupied by the bunch-grass association.

Fig. 2. Face of the river dune, Hanover area, showing the upper and middle slopes, separated by the outcrop of an old soil layer. The thicket association caps the dune in the background.

Plate XVIII.

Fig. 1. Windward margin of the thickets on the river dune, Hanover area. The outermost tree at the left is a green ash. A small *Physalis heterophylla* association in the foreground, at the right.

Fig. 2. Dune thickets on the slope of the river dune, Hanover area. The exposed root system of the ash at the left indicates the migration of the dune

Plate XIX.

Fig. 1. Associations on the river dune, Hanover area. In the right foreground, the deposit association, with a large bunch of *Panicum virgatum* and abundant *Aristida tuberculosa*; behind it, the *Smilacini* association; in the background the dune thickets, with a dense tangle of lianes.

Fig. 2. Margin of the dune thickets on the windward side of the river dune, Havana area. The effect of the migration of the dune is shown in the exposed roots. Forests of the Mississippi river flood-plain in the background.

Plate XX.

Fig. 1. Destruction of the stabilized river-dune and its mesophytic vegetation by river erosion, and the reversion of the vegetation to the pioneer blowsand association. Oquawka area.

Fig. 2. Destruction of the mesophytic vegeta'ion of the river dune by river erosion, showing the coherent surface-layer of sand, and the sliding masses.

BULLETIN

OF THE

ILLINOIS STATE LABORATORY

OF

NATURAL HISTORY

URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. JANUARY, 1911 ARTICLE IV.

FOREST CONDITIONS IN ILLINOIS

Bluffs of Apple River, Jo Daviess County. Red cedar under birch and oak. Sugar maple on left.

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Illinois State Laboratory of Natural History

STEPHEN A. FORBES, Director

In Cooperation with the Forest Service
U. S. Department of Agriculture

HENRY S. GRAVES, Forester

FOREST CONDITIONS IN ILLINOIS

BY

R. CLIFFORD HALL and O. D. INGALL

Forest Assistant and Forest Agent
Forest Service

June, 1910

LETTER OF TRANSMITTAL

Illinois State Laboratory of Natural History,
Urbana, Ill., December 19, 1910.

To the Trustees of the University of Illinois:

I have the honor to submit to you, for publication as a bulletin of the State Laboratory of Natural History, a report on "Forest Conditions in Illinois" prepared by two members of the Forest Service, U. S. Department of Agriculture, R. Clifford Hall, Forest Assistant, and O. D. Ingall, Forest Agent. The study upon which this report is based was undertaken by the Forest Service in cooperation with the State Laboratory of Natural History, the work being done under the direction of Mr. J. G. Peters, in charge of the office of State and Private Cooperation, and under the local instructions of the Director of the Laboratory. By the terms of the cooperative agreement the State Laboratory is authorized to publish the findings of the investigation.

Additional studies of insect injury to forest trees and products throughout the state, made in this connection by one of the assistants of the State Entomologist's Office, will be separately published in the report of that office.

Respectfully,

Stephen A. Forbes,
Director of Laboratory.

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NOTE

Owing to a deficiency of publication funds it has been impossible to reproduce the forestry map mentioned on pages 175 and 176. The statistical data referred to as shown by this map are given in the following table.

Percentages, for each County, of Bottomland, Upland Hill, and Upland Plain in Forest.

County	Bottomland	Upland Hill	Upland Plain
Southern Illinois:			
Pulaski	45	25	..
Massac	50	12	..
Pope	50	18	..
Hardin	..	30	..
Gallatin	20	15	10
White	10	..	5
Wabash	10	..	5
Edwards	10	..	5
Lawrence	8	..	6
Alexander	40	35	..
Union	45	20	..
Jackson	25	20	10
Randolph	12	18	8
Monroe	2	15	10
Johnson	50	35	..
Williamson	40	30	15
Saline	5	20	5
Hamilton	35	..	5
Franklin	50	..	8
Jefferson	..	..	10
Perry	..	..	15
Washington	50	..	5
Northern Illinois:		Upland	
Calhoun	10	15	..
Pike	15	10	..
Jo Daviess	25	12	..

ARTICLE IV.—*Forest Conditions in Illinois.* By R. CLIFFORD HALL AND O. D. INGALL, Forest Assistant and Forest Agent, Forest Service, U. S. Department of Agriculture.

INTRODUCTION

Illinois as a timber-producing state is so overshadowed by Illinois as an agricultural and mining state that little thought is given to the forests as a source of wealth. Yet the output of her sawmills in native timber amounted in 1909 to one hundred and fifteen million board feet,* which represents sawed material alone and excludes such forest products as hewed ties, piling, posts, fuel, and timber for general use on the farm. Evidently the woodlands are of importance as a source of income at least in some parts of the state. Now that the country is beginning to give belated attention to the conservation of all natural resources, the questions naturally arise, what is the extent and condition of our forest lands, and how can they be treated so that they will continue to be productive? The object of this report is to answer these questions for Illinois. It is based on an investigation conducted during the winter and spring of 1910 by the Forest Service, United States Department of Agriculture, in cooperation with the State Laboratory of Natural History. The portion of the state covered in this work may be divided into two parts, one lying south of Centralia and the other along the Mississippi from the mouth of the Illinois to the Wisconsin boundary line. Outside of this territory there are but few areas where woodland covers any extent of country.

An important part of the report is a forest map, showing the broad forest types and their occurrence. These were found to depend on soil and other physiographic features, and, therefore, in determining type boundaries it was possible to use data furnished by the State Soil and Geological Surveys to supplement the field work. Isolated areas of original prairie are not indicated, as these are usually invaded by the surrounding forests. The figures within the boundaries of each type in a county show the percentage of forest land of that type within the borders of the county.

To supplement the description of each of the principal forest types, a table is included showing the proportion of the different species in

*This excludes timber from other states, and hence is less than the figure given in the Census Bulletin, which is 170,000,000 board feet

that type for each county. Trees below six inches in diameter at breast-height were not considered in formulating these estimates. Their chief value is in characterizing the type and showing how it varies in the different counties.

The attention of the reader is especially called to the suggestions given for handling woodland of the different types. It is hoped that these will be of use to owners of woodland, and that reports will be made either to the Forest Service or to the proper state authorities of the results obtained through applying the principles outlined.

General Conditions

The first information published in regard to the extent and distribution of Illinois woodlands is included in a descriptive and historical volume by Fred. Gerhard, entitled "Illinois as It Is," issued in 1857. It consists of a map by Dr. Fred. Brendel, of Peoria, showing the prairies, woods, swamps, and bluffs. The wooded areas indicated on this map have been copied on the forest map that accompanies this report, since they represent, probably with fair accuracy, the original forests of the state. About thirty per cent of the total area is given as woodland.

In 1882 the following information in regard to Illinois forests was published in a book by Robert P. Porter, entitled "The West: from the Census of 1880":

"While Illinois is emphatically a prairie state, it has never been so nearly treeless as the states beyond the Missouri. Large districts of southern Illinois were originally densely wooded, and forest belts from three to thirty miles wide extended along the banks, and filled the areas between the forks of rivers. In many sections large surfaces have been denuded of timber. The woodlands at this time, based on the observations of the State Horticultural Society and the Census returns, stand in about the following ratio to the entire area of the country: In the Fox River District, embracing twelve counties in the northeastern corner of the state, the acreage of woodland is about six per cent of the whole; in the Rock River District, including eleven counties in the northwest, it is now a little more than eight per cent; in the Illinois River District, below Ottawa, extending across to the Mississippi, embracing twenty-one counties, it is not far from fifteen per cent; east of this district in the Grand Prairie District, including seventeen counties in East Central Illinois, it is about six per cent; directly south of this, in the Centralia District, embracing seventeen counties, lying mainly between the Wabash River and the

Fig. 1. Map of Illinois, showing percentage of farm-land in forest in 1880.

Illinois Central Railroad, the woodland acreage rises to fully twenty-four per cent of the entire area; in the Kaskaskia District, stretching eastward of this last to the Mississippi, including thirteen counties, it is twenty-one per cent; and in the Grand Chain District, including the eleven counties in the extreme south, it is from twenty-five to twenty-seven per cent."

The accompanying map, drawn from the above description, will make these figures more easily understood. Since they are based on agricultural statistics of the Census of 1880, they really show the proportion of the farm lands in woods rather than the proportion of woodland to the total area. Since at that time more than a third of some of the southern counties of the "Grand Chain District" was not classed as farm land, and consisted principally of timbered bottoms, the actual percentage of the total area in forest was undoubtedly much higher than indicated. On the other hand, the figures for the more northern prairie country where this condition did not exist seem rather high.

Everywhere the interference of man has disturbed the natural balance between prairie and forest, so that original prairie land has been occupied by tree associations, while far greater areas of original forest land have been cleared and now have the aspect of prairies. The present study shows that there are nearly a million acres of woodland in the twenty-six counties covered by this report. At a rough estimate, there is probably another million acres wooded in the rest of the state, or a little more than three per cent. This would make the present forest area of Illinois about two million acres, or five and one-half per cent of the total land area.

Table I gives a good idea of general conditions in the better wooded portions of the state, although the estimates, especially of standing timber, are only approximations based on an amount of field work too limited to give absolutely reliable and accurate results.

TABLE I.—Showing Area of Forest Land by Counties and Types, with Estimated Amount of Timber 6 Inches and above in Diameter, Breasthigh, in Thousand Cubic Feet.

County	Total area	Area forested	Per cent forested	Estimated stand	Bottomland		Upland Plain		Upland Hill	
					Forest area	Per cent of total forest area	Forest area	Per cent of total forest area	Forest area	Per cent of total forest area
	Acres	Acres		M. cu. ft.	Acres		Acres		Acres	
Southern Illinois:										
Pulaski	122,880	41,940	34	63,430	25,240	60	.....	..	16,700	40
Massac	152,320	34,950	23	46,260	21,930	63	.....	..	13,020	37
Pope	232,960	49,250	21	38,690	11,430	23	.....	..	37,820	77
Hardin	124,160	37,120	30	22,420	260	1	.....	..	36,860	99
Gallatin	208,000	34,330	16	38,170	23,820	70	5,640	16	4,875	14
White	327,680	23,830	7	5,510	14,900	62	8,930	38	.....	..
Wabash	144,640	9,360	6	7,400	4,260	45	5,100	55	.....	..
Edwards	148,480	8,480	6	5,950	2,110	25	6,370	75	.....	..
Lawrence	231,680	14,860	6	9,830	3,820	26	11,040	74	.....	..
Alexander	147,200	55,680	38	72,350	33,280	60	.....	..	22,400	40
Union	256,000	63,950	25	83,710	22,950	36	.....	..	41,000	64
Jackson	357,120	53,700	15	54,300	17,880	33	21,300	40	14,520	27
Randolph	371,200	38,610	10	32,370	6,410	17	20,000	51	12,200	32
Monroe	246,400	22,360	9	16,420	1,620	7	8,190	37	12,550	56
Johnson	217,600	79,890	37	.....	12,450	16	.....	..	67,440	84
Williamson	282,880	47,750	17	.....	2,560	5	37,760	79	7,430	16
Saline	243,200	18,370	8	10,510	1,670	9	8,420	46	8,280	45
Hamilton	280,320	36,760	16	34,710	26,530	72	10,230	28	.....	..
Franklin	279,040	28,560	10	18,620	7,420	26	21,140	74	.....	..
Jefferson	377,600	37,760	10	28,320	.....	..	37,760	100	.....	..
Perry	275,200	41,280	15	24,770	.....	..	41,280	100	.....	..
Washington	355,200	23,560	7	16,280	6,450	27	17,110	73	.....	..
Northern Illinois:					(Bottom-land)				(Up-land)	
Calhoun	161,280	21,520	13	15,680	5,338	25	.....	..	16,185	75
Pike	521,600	59,110	11	45,550	20,865	35	.....	..	38,250	65
Jo Daviess	419,840	54,050	13	43,470	7,060	13	.....	..	46,990	87
Total (26 counties)	6,484,480	937,030	..	734,720	.....	..	.....	..	.....	..

The entire forest area of the state is classed with the Central Hardwood Forest. There are, however, some general differences in forest conditions between northern and southern Illinois. The dividing line may best be taken as the south limits of the middle Illinoisan and early Wisconsin glaciations, and may be roughly indicated as a line from St. Louis to Shelbyville and thence east to the northeast corner of Clark County. South of this line the country was once largely forested, with but comparatively little prairie, while to the north the original forest was for the most part confined to belts following the principal drainage lines. Typical southern species, such as overcup, cow, and swamp Spanish oaks, tulip-tree, cucumber, red gum, tupelo, and cypress, are wanting in northern Illinois. Here the northern hardwoods take the place of these, but the variety of species is not so great. The southern part of the state also contains a larger proportion of absolute forest land, that is, land which is better adapted to timber production than to agriculture.

Forests of Southern Illinois

Soil areas and forest types

The southern Illinois region includes a variety of physiographic conditions. The largest division is the lower Illinoisan glaciation, which extends from the northern limits of the region to the unglaciated highlands which begin near the south border of Jackson, Williamson, Saline, and Gallatin counties. This country is level or undulating, and drained by rather sluggish streams meandering in broad flood-plains. Except where it is broken by bottomlands along the Kaskaskia, Little Wabash, and other rivers, the soil is a thin loess deposit underlaid by a clay subsoil. The corresponding forest type is termed the upland plain type, and is characterized by slower growth and less variety of species than the other types of the region.

Along the Mississippi River bluffs is a fringe of broken country covered with a deep loess deposit, described as a yellow fine sandy loam. The unglaciated area is also a rugged, hilly country, being an extension of the Ozark plateau. Here the soil is chiefly a yellow silt loam. The soil and subsoil are more porous than in the lower Illinoisan glaciation, and consequently more favorable to tree growth. Although there are some minor differences, the forests of the Mississippi bluffs and the Ozark highlands are classed together as the upland hill type. It includes a greater variety of species than any other upland type of the state.

The entire hill region is bounded on three sides by the bottomlands of the Mississippi, Ohio, and Wabash rivers, while it is broken

by overflow areas on such streams as the Kaskaskia, Big Muddy, Cache, and Little Wabash. Sand, silt, loam, or clay may be on the surface of these bottomlands, but the subsoil is usually clay. The forest type characteristic of this class of lands comprises many rapid-growing and valuable species in mixtures varying with the soil and soil moisture.

BOTTOMLAND TYPE

General Characteristics.—The most important trees of the southern Illinois bottomlands are pin oak, elm, sweet gum, the hickories, white oaks, soft maple, ash, willow, and cottonwood. Big shellbark, mockernut, water, pecan, and bitternut hickories are the chief representatives of that genus. Practically all of the lowland white oaks are present, including swamp white, white, cow, overcup, and bur oaks. The following species, while characteristic, are either fewer in number or more restricted in their distribution: cypress, river birch, swamp Spanish oak, hackberry, sycamore, honey locust, coffeetree, black and tupelo gums, and catalpa. The broad level stretches subject to occasional overflow are covered with a mixture in which either pin oak or sweet gum predominates. Wetter situations are often occupied by elm and soft maple. Willow and cottonwood are characteristic of newly-made land, especially along the larger watercourses, while river birch and sycamore follow the smaller streams. The best quality white oaks and shagbark hickory grow where drainage conditions are most favorable, often on low, sandy ridges. There is little underbrush, since as a rule the stands are dense. Where it does occur, it usually consists of tree species, mixed with hawthorn, buttonbush, cat-briar, Hercules club, pawpaw, boxelder, and redbud. Vines, poison ivy, and rank weeds also obstruct passage through the woods.

Mississippi River.—The proportion of forest land for the Mississippi bottoms grows less going northward, varying from forty and forty-five per cent in Alexander and Union counties to twelve per cent in Randolph. North of Randolph the forest is confined to a strip along the river and a few scattered woodlots. The Alexander County bottoms also contain more beech, hackberry, black gum, cypress, and tupelo than those farther north. Sweet gum, which forms twenty-five per cent of the stand in Alexander County, is rarely found north of Raddle in northern Jackson County. On the whole, the Mississippi bottomlands are thoroughly cut over, and few good stands of sawtimber remain. The merchantable timber averages about 2,000 to 2,500 board feet per acre, while the best stands will contain 8,000 to 12,000 board feet.

Kaskaskia River.—The conditions within the bottom forests of the Kaskaskia or Okaw River were studied from Evansville up through Randolph, St. Clair, and Washington counties. The conditions are similar to those* of the same type farther up the river in Clinton and Fayette counties, so the following description may be considered typical for the entire Okaw Forest.

The width of the flood-plain varies considerably, and the largest areas are found generally in the concave side of the stream-meanders or at the mouths of tributaries. Former stream-channels and cut-offs form depressions in the general level, and these depressions are wet throughout most of the year, and at a little higher elevation also there are poorly drained secondary bottoms. Floods cover the whole area to a considerable depth several times a year, but the numbers and times of these inundations vary from year to year, making agriculture on the cleared portions very uncertain.

The forest here varies from that on the bottoms already described chiefly in the absence of sweet gum. It was originally a fine stand of the various bottomland white oaks, hickories, elm, cottonwood, maple, ash, sycamore, pin and shingle oaks, with scattered boxelder, buckeye, honey locust, and mulberry. It has been very heavily culled of the larger trees and the more valuable species, so that second-growth pin and shingle oaks are the predominant trees that grow over considerable areas, in more or less pure stands, on the lands farthest from the stream channel. The other hardwoods are mainly represented by poor specimens, large, crooked, or doty trees, scattered among a fair amount of young growth of all the species mentioned. Good stands of almost virgin forest are found in very scattered and small areas here and there throughout the bottoms.

Big Muddy River.—The Big Muddy River and its tributaries flow through a considerable area of bottomland in Franklin, Williamson, and Jackson counties. Pin oak predominates, forming about a third of the entire forest, while sweet gum is very scarce. Sycamore, elm, and silver maple grow along the water's edge, while the better-drained river banks and the edges of terraces or "second bottoms" are covered with a mixture in which hickory predominates, mixed with bur and white oak, elm, red oak, and sometimes black gum. On the wet ground back from the banks and in the second bottoms, pin oak forms eighty per cent of the stand, and is associated with swamp white and overcup oaks. Hickory, elm, and ash are scattered throughout practically all of these various formations. The forest has been heavily

*Described by Wesley Bradfield in a manuscript on Typical Forest Regions in Illinois.

cut over and will yield on an average only about 1,000 or 1,500 board feet of saw-timber per acre.

Cache River.—The bottoms of Cache River extend through Alexander, Pulaski, and Massac counties, and reach also into southern Johnson and eastern Pope. There is but slight difference in elevation between the upper waters of Cache River and its mouth, and this results in very imperfect drainage. Large sloughs, such as Black Horse in Massac County, are under water practically throughout the entire year. These sloughs are covered with a cypress-tupelo mixture, much like the slough type of the lower Mississippi Valley. The stands are dense, with tall, straight trunks rising high from buttressed bases. Owing to the difficulties of logging, much of this timber is still standing, although most of it is now held by a single company and is in process of removal. Of the bottomlands as a whole, about half are cleared for cultivation, and the more accessible situations have been heavily cut over. Outside of the sloughs the ordinary bottomland types are found. Beech, although not a typical tree on broad bottoms, is found here in considerable amount, both in Pulaski and Alexander counties, but chiefly in the bottoms adjacent to hill lands on the north. The surface soil here usually consists of wash from the hills. Culled forests on the Cache River average about 2,000 board feet of saw-timber per acre, while the virgin stands will run 10,000 board feet over extensive tracts.

Wabash River.—The Wabash River bottom forest differs from that of the Cache River chiefly in the lack of large permanently inundated areas covered with tupelo and cypress. The type extends up the numerous tributary streams, such as the Little Wabash and Embarras. The Saline River, though not a triubtary of the Wabash, is bordered by practically the same type. These bottom areas extend into Gallatin, Saline, White, Wabash, Edwards, Lawrence, and Hamilton counties.

The bottoms of the Wabash and Ohio are quoted in all authorities as the optimum habitat for a great number of the bottomland hardwoods of the eastern United States. In variety and size of trees this region formerly held the record. Descriptions written by Ridgway in the early seventies give a very good idea of the wonders of the virgin forests. He says in part:*

"That portion of the valley of the Wabash River and its tributaries lying south of latitude about 38° 25′ contains a sylva peculiarly rich, and also remarkable for combining within one area many of the characteristic trees, as well as other plants, of the northern, southern,

* Notes on the Vegetation of the Lower Wabash Valley. Robert Ridgway American Naturalist, Vol. 6, p. 658.

and southwestern portions of the United States, besides supporting the vegetation common to the whole Atlantic region or 'Eastern Province.' In this section of the country many species of the botanical districts named, in receding from their several centers of abundance, overlap each other, or reach their latitudinal or longitudinal limits of natural distribution; thus with the beech, sugar maple, the various oaks and other trees of the north, grow the bald cypress, the tupelo gum, and the water locust of the south, and the catalpa and pecan of the southwest; while other trees such as the buckeyes, honey locust, black locust, coffee-bean, etc., especially characteristic of the country west of the Alleghanies, reach here their maximum of abundance. At the same time, other trees of more extended distribution grow scarcely anywhere else to such majestic size as they do here in the rich alluvial bottoms, the deep soil of which nourishes black walnuts, tulip trees, sycamores, white ashes, and sweet gums of astonishing dimensions.

"The mixed woods of the lower Wabash Valley consist of upwards of ninety species of trees, including all of those which reach a maximum height of over twenty feet; these are distributed through about twenty-five orders and fifty genera. In the heavy forests of the rich bottom-lands more than sixty species usually grow together, though in various localities different species are the predominating ones.

"In the heavy forests of the bottom-lands, which in many places have entirely escaped the ravages of the ax, the magnitude of the timber is such as is unknown to the scant woods of the eastern states, the stiff, monotonous pineries of the north, or the scrubby growth of other portions. . . . The approximate height above the ground beneath of the average tree-top level is about one hundred and thirty feet—the lowest estimate after a series of careful measurements—while the occasional, and by no means infrequent, 'monarchs,' which often tower apparently for one-third their height above the tree-top line, attain an altitude of more than one hundred and eighty feet, or approach two hundred feet.

"Of the ninety to a hundred species of trees of the lower Wabash Valley, about seventy exceed the height of forty feet; forty-six (perhaps fifty) exceed seventy feet in height; and about thirty are known to reach or exceed the height of one hundred feet. Of the latter class, as many as nine are known certainly to reach, or even exceed, the altitude of one hundred and fifty feet, while four of them (sycamore, tulip-poplar, pecan, and sweet gum) attain, or go beyond, an elevation of one hundred and seventy-five feet! The maximum elevation of the tallest sycamore and tulip trees is probably not less than two hundred feet.

"Going into these primitive woods, we find symmetrical, solid trunks of six feet and upwards in diameter, and fifty feet, or more, long to be not uncommon in half a dozen or more species; while now and then we happen on one of those old sycamores, for which the rich alluvial bottoms of the western rivers are so famous, with a trunk thirty or even forty, possibly fifty or sixty, feet in circumference, while perhaps a hundred feet overhead stretch out its great white arms, each as large as the biggest trunks themselves of most eastern forests, and whose massive head is one of those which lifts itself so high above the surrounding tree-tops. The tall, shaft-like trunks of pecans, sweet gums, or ashes, occasionally break on the sight through the dense undergrowth, or stand clear and upright in unobstructed view in the rich wet woods, and rise straight as an arrow for eighty or ninety, perhaps over a hundred, feet before the first branches are thrown out."

At present the virgin timber is almost entirely cut off, and the remaining small scattered areas give only a very incomplete idea of the former forests. In these present-day stands, sweet gum, pin and Spanish oak, and elm reach the greatest size and yield the greatest amount of lumber, while the various swamp white oaks, hickories, pecan, ash, and red and Texan oak come next in commercial importance. There are also fair quantities of sycamore, soft maple, willow, and cottonwood, and scattered trees of honey locust, black gum, hackberry, river birch, catalpa, and persimmon.

The virgin stands run as high as twenty to twenty-five thousand board feet per acre on individual acres, but the best average stand over any large area was estimated at thirteen thousand five hundred feet per acre, of which sixty per cent consisted of "softwoods", such as gum, elm, and maple, and forty per cent of "hardwoods," such as oak and hickory. Those areas which have been cut over for the large mills but have not been culled by the portable mills, run from one to two thousand board feet per acre, but after the small mills are through there is no merchantable timber left, and there are now large tracts with nothing but very young growth of gum, pecan, hickory, elm, and maple, and occasional tall, slim trees of the same species.

The type that grows on the tributary stream bottoms of Hamilton, White, Wabash, Edwards, and Lawrence counties is similar to that of the bottomlands of the Wabash River, with the exception of certain areas of tight clay soil, which, though often wet because of poor drainage, are characterized by an open growth of post, shingle, pin, and blackjack oaks. On the whole the various lowland white oaks are more abundant here among the young growth than in the regular

bottoms. Black gum is also present in larger quantities, principally among the older growth, while in some places elm, soft maple, and shingle oak form a characteristic mixture. The forest has been very heavily cut over, first for stave wood and more latterly for the white and "water" oaks. Many ties are now being cut in Hamilton County from the remaining stands of pin and shingle oak.

The bottomlands which are not immediately adjacent to the big streams are not subject to such great inundation, and the soils contain more humus and are thus more fertile. They are easier to convert into good agricultural land, and many drainage projects are now being carried out and the former wet forest lands are being converted rapidly into rich farms.

Silvicultural Conditions.—The silvicultural conditions of the bottomland type are on the whole poor, owing to the repeated culling out of the best trees. Very often a scattering stand of decayed, limby, crooked, or otherwise defective old trees has been left. Although of little commercial value, these trees are allowed to occupy the place that should be taken by thrifty second-growth timber. Where lumbering has more nearly approached the clear-cutting system, the results often have been more favorable, since the young trees, when given room, show very rapid growth. While fire damage was noted in a few cases, the type is, on the whole, free from this source of injury, owing to the wetness of the situation.

Aside from the scattering overmature trees that have been rejected by lumbermen, and a few areas—some of which are quite extensive—where the trees have been injured by overflow and have later been badly infested by insects, the timber is sound and thrifty, and little subject to insect injury or fungous disease. The oaks are much less liable to be attacked by borers here than on the uplands. Hickory and ash are more or less diseased wherever they occur, and ash is very subject to injury by sessid borers on the bottomlands. Ash logs are perhaps the most seriously injured of any timber when left exposed for a season in the woods. Most of this injury is caused by borers of the genus *Neoclytus.*

The young growth on the bottomlands is as a rule abundant, and sometimes forms dense thickets. The usual method of lumbering consists in culling out a certain class of timber at one time and another class at some later time, leaving large or small openings in the forest each time. These openings are seeded to one or several species, and this results in even-aged groups. The resulting stand, therefore, will be, as a whole, many-aged, but composed more or less of even-aged groups, some pure and others mixed, according to conditions. The various oaks commonly reproduce in pure groups of this kind.

The lighter-seeded species, such as ash, elm, hackberry, soft maple, and red gum, are usually more scattered, although maple and gum both frequently form thickets where there is plenty of light. Hickory reproduces in groups and as individuals. Ash is much more abundant among trees of seedling size than among saplings and poles, as the young trees seem especially subject to disease. Maple, hickory (especially bitternut), ash, and hackberry often grow up under the shade of the mature stand and, becoming more intolerant of shade with age, gradually die off unless released by a cutting. Willow and cottonwood seldom reproduce except on moist mineral soil, but come up abundantly on sand bars and newly exposed river flats.

TABLE II.—Showing Estimated Percentage of Species in Bottomland Type of Southern Illinois, by Counties.

County	Cypress	Hickory	Willow	Cottonwood	Birch	Beech	White oaks	Black oaks	Swamp Spanish oak	Pin oak	Shingle oak	Elm	Tulip	Sweet gum	Sycamore	Honey locust	Soft maple	Basswood	Black gum	Tupelo	Ash	Misc.
Pulaski	4	5	1	1	1	3	1	2	..	22	..	10	1	15	2	1	5	..	2	20	2	2
Massac	6	5	1	1	1	3	1	..	..	20	..	10	..	15	2	..	5	1	..	25	2	2
Pope	6	5	1	1	1	3	1	..	..	20	..	10	..	15	2	..	5	1	..	25	2	2
Hardin	..	12	1	1	..	..	5	..	10	15	..	12	..	30	..	..	10	..	..	..	2	2
Gallatin	..	12	1	1	..	..	5	..	10	15	..	12	..	30	..	..	10	..	..	..	2	2
White	..	5	..	..	..	..	15	..	20	30	..	10	..	10	1	..	5	..	..	..	2	2
Wabash	..	6	..	..	..	..	10	10	..	20	..	18	..	20	1	..	8	..	1	..	3	3
Edwards	..	6	..	..	..	..	10	10	..	20	..	18	..	20	1	..	8	..	1	..	3	3
Lawrence	..	5	..	1	..	..	5	3	..	34	..	25	..	8	1	..	14	..	..	..	1	2
Alexander	1	6	1	1	1	2	3	5	..	20	..	18	..	25	2	..	6	..	2	3	2	2
Union	..	5	1	1	..	..	4	6	..	32	..	20	..	18	2	..	6	..	1	..	2	2
Jackson	..	4	..	1	..	..	4	10	..	26	..	20	..	20	2	..	5	..	1	..	4	3
Randolph	..	6	1	1	..	..	6	6	..	50	..	15	..	..	1	..	8	..	..	..	4	2
St. Clair	..	10	..	..	3	..	10	..	..	40	3	15	..	..	2	..	10	..	..	..	5	2
Johnson	4	5	1	1	1	3	1	1	..	22	..	10	1	15	2	..	5	1	1	22	2	2
Saline	..	12	1	1	..	..	5	..	10	15	..	12	..	30	..	..	10	..	..	..	2	2
Hamilton	..	5	..	..	..	..	15	2	..	50	..	4	..	15	1	..	5	..	..	..	1	2
Franklin	..	18	..	..	1	..	10	3	12	30	..	8	..	3	1	..	8	..	..	..	3	3
Washington	..	10	..	..	2	..	4	..	..	50	15	8	..	..	1	..	6	..	..	..	2	2

UPLAND HILL TYPE

The Ozark Hills region of southern Illinois, an extension of the Ozark Plateau, lies in the angle formed by the Ohio and Mississippi rivers, and is bounded on three sides by bottomlands. On the north, these highlands rise from the undulating upland plain, sometimes abruptly, sometimes gradually. In addition to these unglaciated hills, there is a narrow strip of rough country along the Mississippi River with similar topographic features and forest growth. The east boundary of these bluff lands is not distinct, as the topography becomes less broken in character eastward until it merges into the upland plains. The line which marks this east boundary is drawn somewhat arbitrarily on the map, and separates off a strip of hilly country three to seven miles wide.

In general the forests are confined to the slopes, since the ridges and creek bottoms are usually under cultivation. However, there are sections of very rough land in eastern Alexander, Union, and Jackson counties, and in northern Pope and Hardin, that are almost completely wooded. Here the ridges are sharp and narrow, with numerous spurs, interlaced with a maze of steep-sided valleys. While the underlying rock seldom outcrops in large exposures, these higher ridges are often carpeted with small stones. Ordinarily, too, timber grows in the sink-holes that characterize the limestone section of Randolph and Monroe counties, back of the bluff line, and of Hardin County, northeast of Cave-In-Rock.

The forests of these two hill sections cover from twelve to thirty-five per cent of the surface. They differ from those of the more level uplands, not so much in the identity and proportion of the principal species as in the greater variety of minor species and the better development of the timber. The oaks and hickories together predominate, and form, respectively, about sixty and ten per cent of the stand. In the southern counties on the Ohio and Mississippi rivers (Pulaski, Alexander, Union, and Jackson), beech constitutes from fourteen to thirty-eight per cent of the forest, but is rare elsewhere. It grows in cool hollows and on north and east slopes. Black, Spanish, red, white, post, and chinquapin are the principal oaks, but scarlet and blackjack also characterize the stands. Pignut, mockernut, and shagbark are the chief hickories. Other characteristic trees are butternut, black walnut, elm, mulberry, cucumber, tulip-poplar, red gum, black cherry, coffeetree, black locust, sugar and silver maple, black gum, and ash. The typical trees of the southern bottomlands grow on the moist lower slopes and along the creeks. The richer slopes support a mixture of white oak, red oak, tulip, cucumber, and nearly all the trees of the region; while drier situations, such as upper slopes and

low ridges, are dominated by the black oaks and hickory. The sinkholes of Randolph, Monroe, and Hardin counties support a mixture similar to that of the better slopes.

In many places the drier slopes and upper south slopes are covered with post oak, mixed with blackjack, black oak, and pignut hickory. Red cedar forms an understory of small trees with the post-oak type of the ridges in Hardin County. The high ridges in the western part of the region are sometimes covered with a scrubby growth of black oak and black gum instead of the usual post-black-blackjack mixture.

The precipitous bluffs that are found in many places along the Mississippi and Ohio rivers are often almost bare of vegetation of any kind. Small red cedar is a common tree on such situations, especially on limestone cliffs. It is often associated with black locust and a scattering of other scrubby hardwoods.

An interesting feature of this region is the occurrence of shortleaf pine on the broken land along the bluffs of the Mississippi River in Union County, beginning a little north of Wolf Lake and extending to southern Jackson County. The trees are small, mostly from six to fourteen inches in diameter, and grow on the stony upper slopes in mixture with black and white oaks and other hardwoods. This is the only place in the state, as far as known, where southern pine is indigenous, although the same species is abundant and of economic importance in parts of the Ozark Plateau of southern Missouri.

The undergrowth characteristic of the hill lands is a mixture of young trees, especially hickory and oak, with such shrubby species as dogwood, sumach, witchhazel, and redbud. Blue beech and ironwood are common along drainage lines.

The hill forests, like the bottomlands, have suffered from repeated culling of the more valuable trees. The insect damage is much greater. Practically all the more important species are attacked more or less seriously, with the exception of the tulip. An insect which is found in over ninety per cent of all young white oaks, causes considerable loss by injuring the quality of the wood while not seriously affecting the growth. Frequently, young trees of nearly all species are killed or badly deformed by insects during the first fifteen years of growth. Those that suffer least during this period are maple, tulip, and beech.

It is a common practice to use woodland of this type for pasture, and in some localities this has had an appreciable effect in keeping down young growth. In the majority of cases, however, grazing has not been heavy enough to seriously damage the stand.

TABLE III.—Showing Estimated Percentage of Species for Hill Forest Type of Southern Illinois, by Counties.

County	Hickory	Beech	White oaks	Post oak	Black oaks	Pin oak	Black-jack oak	Elm	Tulip	Sweet gum	Sycamore	Hard maple	Soft maple	Black gum	Ash	Misc.
Pulaski ..	4	14	30	..	35	2	..	1	1	4	..	..	2	3	1	3
Massac ..	10	..	15	8	30	10	1	5	2	5	..	1	2	2	7	2
Pope.....	10	..	25	2	30	..	1	3	3	5	..	4	..	2	12	3
Hardin ...	14	..	22	2	42	..	..	2	3	5	1	2	..	2	2	3
Gallatin ..	12	..	24	2	40	..	1	3	3	5	1	2	..	2	2	3
Alexander	2	38	20	..	30	1	..	..	1	2	..	..	..	2	1	3
Union....	12	24	20	2	30	1	..	1	1	..	..	..	..	3	4	2
Jackson ..	12	18	22	2	33	2	..	1	1	..	..	..	..	3	4	2
Randolph	12	..	28	2	36	2	..	8	..	..	..	..	1	5	4	2
Monroe...	10	..	24	5	44	4	..	4	..	..	1	..	1	2	2	3
St. Clair ..	10	..	24	5	44	4	..	4	..	..	1	..	1	2	2	3
Saline. ...	10	..	25	2	38	..	1	2	3	3	..	3	..	2	8	3

UPLAND PLAIN TYPE

The region covered by the lower Illinois glaciation lies north of the Ozark Hills and west of the Mississippi bluff land, and is characterized by distinct forest types. The topography is smooth, with little or no rock outcrop, and varies from flat plains to undulating or gently rolling country cut by the shallow valleys of small streams. The soils are inclined to be sour and to be inferior in fertility.

The forest is characterized by the preponderance of oaks. It may be divided into two subordinate types which depend on the soil and topography for their distribution, but which are so intermixed as to preclude the possibility of separating them on the map. Each of these has within itself many minor variations in composition, dependent on the variations in local conditions.

Oak-Hickory Type.—The oak-hickory type is composed principally of the black oaks, white oaks, and hickories. It is found on well-drained, undulating country having a yellow-gray or yellow silt loam soil. The forests of this type are generally in the form of small woodlots, and are held as sources of wood supply for individual farms. They are largely situated on broken land along stream valleys least suited to agriculture. The conditions of density and form are variable. Sometimes the forest takes the form of an open grove used as pasture for cattle or hogs, and sometimes that of a dense woodland with underbrush and a good amount of young growth.

Black oaks generally exceed the white oaks in volume, but in second-growth stands the latter not uncommonly predominate because of their excellent reproduction. The stands are for the most part second-growth, of seedling or sprout origin, often with scattered veterans of the virgin stand. Virgin stands of even small extent are rare, and when present are along the small stream valleys or on slopes too steep for agriculture.

The rate of growth of these forests is comparatively good, though slower than on the bottoms. Reproduction is also excellent, except where fire or heavy grazing has prevailed. The poorer sites generally have a great deal of hickory among the young growth, but on the better soils and under good conditions the oaks predominate. The large proportion of young white oak, a condition unusual in so many other hardwood forests, is very encouraging. The young trees are generally in small groups, in openings made by former cuttings.

Fire and grazing have done a great deal of damage. Reproduction is rendered impossible, young trees are seriously injured or killed, and the humus content of the soil is often very much reduced. Insects, while present in fairly large numbers, have not infested the thrifty vigorous trees which have not been weakened by fire. About seventy-

five per cent of the black oak and from twenty-five to fifty per cent of the white oaks are infested by borers. Young hickories and elms are especially subject to attacks of the hickory twig-girdler, which often spoils their form by destroying the leader.

A slight variation of the oak-hickory type is found along the bottoms and gentler slopes of the small stream valleys. The mixture in these situations is more complex; white oaks are apt to predominate, and many trees of the bottoms are found. The white oaks include overcup, bur, chinquapin, cow, swamp white, and white oak. There are also black oaks, including black, red, and pin oaks, hickories, elm, black and sweet gum, ash, birch, sycamore, honey locust, and walnut.

Post-Oak Type.—The other type of this region may be called the post-oak type. It is found on what is known locally as "postoaksy" flats. The usual soil is a light gray silt loam on a tight clay subsoil, very impervious, but not a true hard-pan. Drainage is poor and a sour condition prevails. Perhaps the largest and most continuous area is found in the north of Perry and the south of Washington counties, but it is scattered throughout Franklin, Jefferson, Monroe, and St. Clair counties in areas of considerable extent, and to a lesser degree is found in all the other counties of the region. It is often typical of the edge of the true prairie.

The prevailing forests are open stands of post and blackjack oaks, a few hickories, with occasional patches of pure growth of shingle or pin oak, especially where the ground is wet. The trees are poor in form, with short, rapidly tapering trunks. Blackjack never reaches any considerable size, but the occasional black oaks that are found in the mixture, together with the post oaks, attain merchantable diameter. Shingle oak also makes a very fair growth on these soils.

These post-oak flats are frequently cut clear for props or posts, so that the younger stands are often even-aged. Since fire has frequently followed the cutting, sprout trees predominate greatly over seedlings. Often this young growth forms quite dense thickets, and where fire has been through, the proportion of blackjack is perhaps nearly equal to or even more than that of post oak,—a condition the reverse of the older stands, where the amount of post oak is many times that of blackjack. Pin and shingle oaks are generally of seedling origin. Growth on the whole is very slow.

Fires have done a great deal of damage in this type, for a number of reasons. The great amount of brush left after clear cutting, the dryness of the soil, and the large contiguous wooded areas, tend to make fires prevalent. Since the soil is naturally poor in humus, the injury in burning out the leaf mulch is all the more severe. The formation of a dense sod and the growth of brush after these fires, combined

with grazing, tends to make seedling reproduction rare. Insect damage is large among all trees in this type of growth, especially the blackjack, which is rarely sound. The trees which have been injured by fire are more subject to attack than the others.

This type often mingles with the oak-hickory type, and a transition zone mixture results, which has the characteristics of both in modified form.

TABLE IV.—Showing Estimated Percentage of Species in Upland Plain Type of Southern Illinois, by Counties.

County	Hickory	White oaks	Post oak	Black oaks	Pin oak	Black-jack oak	Shingle oak	Elm	Tulip	Sweet gum	Sycamore	Hard maple	Soft maple	Ash	Misc.
Gallatin	12	14	25	30	5	2	2	3	..	2	1	..	..	2	2
White	8	35	8	40	1	..	..	2	..	2	..	..	..	1	3
Wabash	10	28	5	32	1	..	5	5	1	4	..	2	1	4	2
Edwards	8	25	10	35	1	..	5	4	..	3	..	..	1	5	3
Lawrence	10	20	5	46	5	2	2	3	1	..	..	..	3	..	3
Jackson	15	22	18	22	3	8	4	1	..	2	1	..	1	1	2
Randolph	10	12	30	18	2	14	5	2	..	3	1	..	1	..	2
Monroe	10	6	30	20	5	15	8	2	..	1	1	..	..	..	2
St. Clair	10	6	25	25	5	15	8	2	..	1	1	..	..	..	2
Saline	12	14	25	30	5	2	2	3	..	2	1	..	..	2	2
Hamilton	8	20	24	40	1	2	3	..	..	..	..	..	..	..	2
Franklin	14	12	28	30	1	8	5	..	..	..	..	..	..	..	2
Jefferson	10	25	20	30	2	5	4	1	..	..	..	..	..	1	2
Perry	10	12	30	18	2	14	5	2	..	3	1	..	1	..	2
Washington	10	15	32	20	2	8	5	2	..	..	1	..	1	1	3

The Early Wisconsin Terminal Moraine

The region of the early Wisconsin terminal moraine separates the northern prairies of Illinois from the more broken rolling upland to the south, and forms part of the boundary between the northern and southern Illinois regions, as described in this report. From its top, the view to the north shows a level prairie, while to the south there stretches a rolling country cut by the stream valleys which flow south and southeast to the Wabash River or south and west to the Kaskaskia. The moraine may be located roughly as a belt which starts in the east near Paris and sweeps around in a curve through Kansas, south of Charleston, Mattoon, and Windsor, and turns north through Macon and near Decatur.

The chief streams that cut through this country are the headwaters of the Embarras in the central part and the Okaw in the northwest. The main streams flow through rather deep, narrow, steep-sided valleys with some rock outcrops near the bottoms. These deep valleys are confined, however, to the transition country where it changes from the level prairies at the north to the lower level land at the south, while farther back towards the upper waters of the small streams the valleys are broad and shallow.

The moraine shows no very distinct line of demarkation from the prairie to the north, but embayments of the latter mark a rather indefinite, irregular boundary. To the south there is again more prairie land at a lower level, with the descent between the two altitudes broken up by the relatively deep valleys which the streams are compelled to cut to adjust their grades.

Studies of the forests were made near Paris, Kansas, Charleston, Mattoon, and Windsor, and are chiefly of interest in showing the mixture typical of the edge of the prairie and of the stream valleys which cut into the prairie.

The forests of the level country to the north and south of the morainal belt are of similar composition, and are in small woodlots which dot the prairie edge here and there. They are of a type which is rather unique and confined to the level land, being the advance growth of the forest as it encroaches on the prairies.

These woodlands are often referred to as "oak openings," and are differentiated by the occurrence of shingle oak. Sometimes it is found in pure stands, but more often in mixture with elm, honey locust, white and black oaks, hickory, and ash; more rarely with pin oak or hackberry.

The forests of the rougher morainal country along the stream valleys, and sometimes extending back to some extent on the more rolling portion of the uplands, are of types that are characteristic of

the rough land farther south. The chief trees are the familiar black and white oaks and hickories, with a considerable amount of hard maple. Bur oak here grows on the higher situations, though with a tendency to choose the moister places, and white ash, walnut, and cherry are also found in considerable numbers. The few persimmons noted in this locality show a tendency to grow on high and dry sites. The narrow bottoms and stream borders support a growth of bottom-land white oaks, elm, sycamore, willow, and a few soft maple. Other trees sometimes found in these mixtures are black gum, basswood, and mulberry. To the east the valley of the Wabash seems to have a controlling influence on the type, which is shown by the presence of beech, tulip, and some small butternut,—all, trees which were not noticed farther west.

South of Vermilion and Paris there is much rough land with steep-sided valleys. Here the woods are large in extent, and consist of a mixture of white, overcup, chinquapin, black, red, and shingle oaks, beech, hard maple, basswood, hickories, ash, tulip, and black walnut, with sycamore, elm, and willow immediately along the stream bottoms. Other species are pin oak, cherry, buckeye, butternut, and an undergrowth of hornbeam and water beech.

Much of the woodland is pastured, and reproduction is generally poor under such conditions, but is excellent where fire and cattle are excluded. Seedling hickories and hard maples are especially thick among the young growth, and shingle oak is common in the type of the prairie borders.

On the edge of the prairies the woodlots are likely to be in better condition than those of the rougher country. The latter are generally uneven-aged cut-over stands, with a greater proportion of young second-growth and few scattered veterans. On the whole, the growth is very good, and a little management would put all the woodland into good shape.

The beech seems to be suffering from a shot-hole fungus of the leaves, and the shingle oak in places is dying, possibly from too much exposure and a change in conditions due to clearing. Farmers in the district complain of the dying of the white oak, which they attribute to a borer. This does not seem to be the real cause, which is probably old age, since the big trees in the stands are usually overmature and stagheaded.

Too heavy cutting on steep slopes, which are absolute forest land, has resulted in the formation of very deep gullies, some of the worst results of erosion.

Forests of Northern Illinois

EXTENT OF THE INVESTIGATION

The original forests of northern Illinois region were in two irregular belts, one extending up the Illinois River and the other up the Mississippi. All of Calhoun and Pike counties were forested, with the exception of small areas of "prairie bottom" on the Mississippi. Most of Jo Daviess County was also wooded, as well as large parts of Carroll, Rock Island, Mercer, Adams, Brown, Schuyler, and Fulton counties. Since the forest land is now confined to overflow lands and broken country along the rivers, it was not advisable to study many of the northern counties in their entirety. After complete surveys of Calhoun and Pike counties, the Mississippi bluff- and bottom-lands were followed northward, without covering an entire county, until the northernmost—Jo Daviess—was reached. Since the woodland elsewhere in the region is very scattered, it was not studied.

BOTTOMLAND TYPE

The principal bottomlands included in this study extend up the Illinois River to Beardstown, and up the Mississippi from the mouth of the Illinois to the north boundary of the state. The usual clay soil gives way in places to large flat plains or slightly elevated bars of pure sand. Where unprotected by levees, portions of the flood-plain are under water for a large part of the year, and in addition there are long sloughs and lakes that are never dry. It is a matter of common knowledge that the floods on the Illinois have been increased through the elevation of the stream level by the additional water from the Chicago drainage canal.

The progress of levee-building and drainage has been such that very little forest land is left. This is largely confined to strips of sandy or very wet soil and to land outside of levees or where such protections have not yet been constructed. The principal species are pin oak, white elm, maple, cottonwood, birch, ash, sycamore, and willow. Bur oak, buckeye, boxelder, hackberry, and honey locust grow scatteringly. The greater part of the forest has been very heavily culled, and in places the lumbering has been practically a clear cutting; reproduction is sometimes very scanty. Those areas of woodland which were lumbered more than a decade ago were for the most part not cut so closely, and have grown up to a dense small growth. Elm, soft maple, ash, pecan, cottonwood, and pin oak comprise most of the stands on the Illinois bottoms. The pin oak is especially noticeable here on account of its tendency to form a dense, even-aged seedling stand

wherever scattered seed-trees have been left after lumbering. Pin oak is less abundant on the Mississippi, where it has been very closely cut for fuelwood. It naturally diminishes in numbers toward the north and is rare beyond Dallas City. Silver maple, white elm, cottonwood, and willow predominate where the oak is lacking, and usually form dense stands. White elm is the chief tree on drier situations, and maple on the wettest flats. There is very little merchantable timber left, and a comparatively large amount of it is on the Illinois, where a lumberman familiar with the territory estimates that there is about 15,000,000 board feet of all species from Chillicothe to the mouth of the river.

TABLE V.—Showing Estimated Percentage of Species in Bottomland Type of Northern Illinois, by Counties.

County	Hickory	Willow	Cotton-wood	Birch	White oaks	Pin oak
Calhoun	2	4	18	1	1	25
Pike	4	2	14	1	3	24
Jo Daviess	..	22	10	..	..	..

County	Elm	Syca-more	Honey locust	Soft maple	Ash	Misc.
Calhoun	22	8	1	10	5	3
Pike	26	8	1	12	3	2
Jo Daviess	28	10	..	22	5	3

On the Illinois River and its tributaries much timber has been killed by the flooding which has followed the opening of the drainage canal. In addition, the ordinary insect and fungus enemies that thrive in heavily cut-over and neglected forests have done their work. Elm and ash are especially subject to insect injury, while pecan and ash are liable to be damaged by a dry rot. Elm and sycamore are likely to be decayed, at least at the butt. Pin oak, while more free from disease than the others, is somewhat liable to wind-shake.

Sand Dunes.—Exceptions to the general forest type found in the bottoms of the Mississippi and Illinois rivers are the sand plain and sand dune formations from about Burlington, Iowa, to Savanna on the Mississippi, and from Florence to Pekin on the Illinois River.

A general discussion of the glacial geology and studies of the ecological and zoological relations of these areas will be found in a bulletin by Messrs. Hart and Gleason.*

These areas are characterized by a rather coarse sand which contains but little plant food and is being constantly shifted by the wind. In places it forms low hills and dunes above the flat plain of the bottoms. In some localities the sand has encroached on the upland, forming dunes on the edge of the original clay bluffs. In others it forms extensive level or gently undulating plains. It is everywhere characterized by wind forms such as "blowouts" and traveling dunes. Parts of it have no vegetation, and a great deal is covered with various grasses. The forest typical of this soil has a very light crown cover, and consists of small short trees of a generally scrubby appearance.

This sand-dune forest type varies in the mixture of species. Along the Mississippi it consists largely of black oak, with some hickory and blackjack. On the Illinois bottoms it seems to run more to blackjack oak, with less black oak and hickory.

The trees are small, short-boled, and where they have been cut over or badly burned, the resulting sprouts form a dense stand of "brush." In some places black oak reaches fair size and would be merchantable for ties. Most of the growth, however, is suitable only for cordwood, and is seldom more than six inches in diameter, breasthigh.

The land is generally pastured and is frequently burned in an endeavor to hasten the spread of the scanty grass cover. Because of the dry top-soil, fires start easily and are very harmful. Much of the land has been clear cut for firewood, and is now covered with an even-aged stand of sprouts, six to ten vigorous shoots to every stump.

This should be considered absolute forest land, since the attempts at agriculture have been generally unsuccessful and the constantly shifting sand menaces the fertile bottoms near by. Some fields have four to six inches of sand blown over them in the course of one winter; and passage over any of these plains on a windy day subjects a person to a veritable rain of sand. If this land were kept under a permanent forest cover, the shifting of sands would stop and the soil eventually become fertile. But it would have to be managed for wood crops exclusively and protected from fire and grazing. At first some planting would be necessary.

* Bull. Ill. State Lab. Nat. Hist., Vol. VII, Article VII. Urbana, Ill., Jan., 1907.

UPLAND TYPE

With the exception of two areas, one covering Jo Daviess County and the other extending over Calhoun County and into Pike, the uplands of northern Illinois are glaciated. There is a wide variety of soils, both of residual and glacial origin. The topography is rolling near the rivers, with level prairies between. The larger streams have cut rather deep, steep-sided valleys, often exposing rock outcrops in the form of precipitous cliffs. Some of the river bluffs are not so abrupt, and the underlying rock is covered by deep loess deposits, wind-driven from the bottoms, which form areas of rounded topography and deep soils. These situations are usually stripped of the original forest cover.

The forests of these northern uplands are similar in many ways to the oak-hickory type of the southern region, and along the river bluffs they resemble to a certain extent the upland hill type. There are, however, no post-oak flats, with the exception of a few areas in northern Calhoun and southern Pike counties, and there are several species peculiar to the northern part of the state. An increase in the proportion of basswood, black walnut, cherry, and sugar maple is the characteristic change from south to north; and as the extreme north is reached, the presence of aspen, black birch, paper birch, and even a sporadic occurrence of white pine, marks the overlapping of more northern tree associations. Some species show a decided change of habit toward the north, as the bur oak, which, while common on the lower bottoms of the Illinois River, becomes a characteristic upland tree in Jo Daviess County, and the red elm and cottonwood, which are found on higher and drier ground than in the south.

The timber of this region is almost entirely in the form of farm woodlots, usually of small size. Although some few occur on the more level land, the majority are found on the steeper valley sides. As a rule, they have received more care than the southern woodlots, and the resultant stands are better. This is not true, however, of the woodlands along the bluffs and within easy reach of the Mississippi River. These slopes have been cut over frequently to provide lime-kilns with fuel, and now the growth is very scrubby.

The predominating upland trees are black and white oaks in about equal proportions. These two groups are represented on the better and deeper soils by red and bur oak, respectively, while on the ordinary wooded uplands, black, scarlet, and white oaks are most common. A very small proportion of hickory is usually associated with the oaks. Along the stream valleys the mixture is varied by white elm, sugar maple, walnut, sycamore, hackberry, and honey locust. The river

bluffs, even where they are thin-soiled and rocky, are characterized by a great variety of species, probably due to the nearness of the bottoms and to the increased atmospheric moisture. Various mixtures of the following species are found on these bluffs: white, black, and bur oaks, white and red elm, walnut, butternut, ash, hickory, sycamore, honey locust, sugar maple, cottonwood, buckeye, coffeetree, and juniper or red cedar. In the vicinity of Rock Island, basswood and cherry begin to form an appreciable part of the stand, and farther north, toward the "driftless area," aspen begins to come in. White pine grows on the bluffs of the Rock, Apple, and Galena rivers.

Tree growth is rapid on most of the northern Illinois soils, and the stands are generally thrifty and free from extensive insect or fungous injury. Many woodlots are not restocking because grazing prevents young growth from getting a start. In most sections the forest fire problem is fully within the control of the individual owner, who is, unfortunately, not always well informed as to the effect of burning over his woodland.

Calhoun and Jo Daviess Counties

The largest proportion of forest land is in the rough, unglaciated areas of Calhoun and Jo Daviess counties. Conditions in these counties are therefore of special interest.

Calhoun County is a long and narrow strip of land lying between the Mississippi and Illinois rivers. The country rises high above the bottomlands in precipitous cliffs, and is cut up by the many short and steep tributary valleys so that there is little level land. The well-drained fertile soils support on the gentler slopes flourishing apple orchards and farms, and on the steep valley sides and bluffs a forest growth composed of a wide variety, mostly of small trees. Black, red, and white oaks predominate, but on the lower slopes sugar maple, basswood, buckeye, and many other species are represented.

Jo Daviess County covers the northwest corner of the state, where the highest elevations are. With the rest of the "driftless area," so famous among geologists, it escaped glaciation and presents a rugged surface with soils for the most part of residual origin. The drainage system is well developed, with steep valley sides; and long, irregular mounds or ridges rise above the general level of the rolling uplands. Except for the northeast corner, the original forest was unbroken, but now only about thirteen per cent of the county is wooded.

In composition, the forest differs somewhat from that of the southern counties. There is more bur oak and cottonwood on the uplands, as well as an increased proportion of walnut, red elm, and

cherry. Aspen is also present in small pure stands, while paper and black birch occur in considerable numbers, but are generally of small size. However, the principal trees that characterize the mixture are black, scarlet, and white oaks. The proportion of hickory and basswood is small. Sugar maple grows singly or sometimes in pure stands of limited extent on the more favorable bluff lands.

TABLE VI.—Showing Estimated Percentage of Species for Upland Type of Northern Illinois, by Counties.

County	Black walnut	Hickory	Cottonwood	Aspen	Birch (black, sweet)	White oaks	Bur oak	Black oaks	Elm
Calhoun	1	5	..	..	..	30	..	45	5
Pike	1	10	..	..	..	30	..	40	5
Jo Daviess	3	7	1	2	3	20	10	35	6

County	Sycamore	Cherry	Honey locust	Hard maple	Soft maple	Buckeye	Basswood	Ash	Misc.
Calhoun	1	..	2	1	1	1	4	1	3
Pike	2	..	2	1	1	1	4	1	2
Jo Daviess	..	1	..	3	..	..	4	2	3

The bluffs along the Mississippi, with their many high cliffs and fantastic rock forms, are cut by narrow, steep-sided tributary valleys which are largely wooded, excepting the narrow bottoms. The same type of topography on a much smaller scale is carried up along the Galena and Apple rivers. While many of the stands on this rough land are in good condition, the majority of them have been either very heavily cut over or clear cut and now are nothing but young growth of a brushy nature. The edges of the cliffs and rocky ridge tops are very conspicuous because of the great number of small juniper or red cedar which form open stands on such sites.

Back of the bluffs the country is rolling, with characteristic high ridges marking the chief divides. The table-lands and more moderate valley slopes are under cultivation, but the steeper slopes and narrow ridge tops are generally completely wooded. The stands are mostly of small second growth, suitable only for products such as ties, posts,

and cordwood. The form of the trees is very good wherever the density is great enough to encourage height growth, but those on the poorer sites, such as exposed cliff sides and rocky ridges, are short and gnarled. On the gentler slopes at the foot of the ridges the woods have been opened up to allow of pasturing, and the result is a very open stand of rather short-boled, large-crowned trees. Bur oak is especially prominent in such stands. Many slopes have been cleared unwisely, and erosion has resulted. The prevalence of grazing has reduced reproduction, especially of seedling origin, and fire has been frequent enough to kill much of the young growth. Insect infestations have been rather extensive, especially among the hickories.

Distribution of Tree Species

The distribution of species is governed chiefly by climate and physiography, but other less stable factors exert an influence, with the result that exceptions can often be found to any general rules that may be laid down. A species will occasionally be found entirely out of its natural range, the seed coming from a cultivated specimen, or through the travel of mankind.

The southeast portion of Illinois, along the Ohio and Wabash rivers, is the richest in number of species, and in this respect is not surpassed, or perhaps not even equaled, by any region of the United States. There are about one hundred different trees found in this part of the state. The valleys of the other large rivers, such as the Mississippi, Kaskaskia, Illinois, and Rock, also contain a great variety of species. Toward the north, the number of species grows less, although there are some, belonging to a more northern flora, which do not occur at all in the south. Many southern lowland trees reach the limits of their normal range along stream valleys, as such situations afford shelter and favorable sites on which to grow. On the other hand, others, such as bur oak, which in the south ordinarily grow on wet situations, extend northward on higher, better-drained sites.

The Illinois forests are composed almost entirely of hardwoods, while conifers are few in number and generally restricted in occurrence. The only evergreens that grow throughout the state are the two sparsely distributed species of juniper, one of which, the dwarf juniper, is seldom more than a shrub. The only commercially important native conifer is the bald cypress, which is found in the bottoms of the Cache and Ohio rivers in fairly large quantities. In the south, there is also the shortleaf pine, which is confined to small stands along the bluffs of the Mississippi, from opposite Wolf Lake, in Union County, to the southern borders of Jackson. In the north, white and

jack pine are occasional, the latter along the Wisconsin boundary, and the former extending as far south as Ogle County and the valley of Rock River. Tamarack and arborvitæ grow near the northern boundary, on low ground.

Among the hardwoods, the oaks and hickories lead in number of species, in number of trees, and in amount of wood. There are nineteen species of oaks and nine of hickories. Among the other important genera that are well represented is the ash, with five species widely distributed. All the important maples are included in the five different species, most of which are widely distributed and on the lowlands often form a large part of the forest. Practically all the important species of elm are found in large quantities, the white and red elm occurring throughout the state, while the winged elm is restricted to the south and the cork elm to the north. Among the true poplars, the common cottonwood is very widespread, while the trembling and largetooth aspens are northern species, and the swamp cottonwood is confined to the extreme southern bottoms. The poplars also are often cultivated, and white poplar (*Populus alba*) and black poplar (*P. nigra*), which have been introduced chiefly for roadside planting, sometimes escape from cultivation. Lombardy poplar (*P. nigra* var. *italica*) is also a common decorative tree, and is very distinctive in form. The willows seldom reach much importance commercially, or from the standpoint of size, but have a wide range and great variety of species. There are two exotics that are commonly cultivated, namely, the white willow (*Salix alba*) and the weeping willow (*S. babylonica*). The black walnut was originally both widespread and fairly abundant, but only the smaller sizes are left, and it is very scattered because of the great demand for it in the timber markets. Butternut is also found throughout the state, but seldom grows to large size, and is very sparsely scattered throughout the forests. The principal representative of the birches is the river birch, which grows in the south along the streams. Paper birch occurs in the extreme northern part of the state. Hornbeam and blue beech are very widely distributed. Beech is found chiefly in the cool valleys of the Ozark Hills, but extends north to some extent up the streams, especially of the Wabash River system. Hackberry grows everywhere throughout the state, but most on the southernmost bottomlands. The sugarberry of the same genus is rarely found except as a shrub or bush, and is confined to the south. Mulberry is very scattered, with few large specimens, partly because it is eagerly sought after for fence posts. Osage orange, while out of its natural range, is everywhere very largely used for hedges, and in some places has escaped from cultivation. The cucumber-tree is confined to the southern hill forests

and is nowhere very abundant. Tulip-poplar is widely distributed in the southern half of the state, and reaches its best development in the Wabash and Ohio valleys. Sassafras grows everywhere, often in old fields, and very seldom as a large tree. Sweet gum is common throughout the southern bottomlands, and reaches its best development there. Sycamore is everywhere characteristic of the banks of streams, and reaches enormous dimensions in the Wabash-Ohio basin. The various species of crab, thorn, haw, and plum trees belonging to the three genera, *Pyrus, Crataegus,* and *Prunus,* never reach large size, and are generally found as an understory to the larger trees. The one exception to this rule is black cherry, which reaches merchantable size and forms an appreciable part of the stand in many mixtures, especially in the north. The honey and water locusts occur on the better soils, and sometimes grow large enough to make sawtimber. Black locust, though not in its natural range, has escaped from cultivation and naturalized itself very widely. Ailanthus is an exotic which has been widely planted, and is now growing wild in some localities. Ohio buckeye is fairly common, but not abundant, along the valley sides of the larger rivers, and sometimes on bottoms, while yellow buckeye is comparatively rare. The coffeetree is a widely distributed but infrequent tree, found in much the same situations as the buckeyes. The basswoods or lindens are also throughout the state, but do not often form any great proportion of the stand, except in the north, where in limited localities they grow in fair quantities on some of the bottoms of the smaller streams. Black gum occurs over a greater part of the south and central part of the state, where it often forms an appreciable part of the forests; while tupelo gum, although found in considerable quantities, is confined with cypress to the extreme southern bottoms. The common catalpa (*Catalpa catalpa*) is a naturalized species, but the hardy catalpa (*Catalpa speciosa*) is native on the southern bottomlands, where it once attained considerable size and commercial importance as a post timber. It is now largely used for planting. Pawpaw and persimmon occur commonly as small trees or bushes. The former is more restricted in range than the latter, occurring most abundantly in the southern third of the state.

Many other species, such as the sumachs, hornbeam, blue beech, witchhazel, redbud, wahoo, dogwood, and viburnums, are found as small trees or bushes that form an understory in the forest.

The following list shows one hundred and twenty-nine tree species found in Illinois. This number includes a few that are seldom more than bushes. On the other hand, it omits many species of *Crataegus,* and perhaps a few of *Pyrus* and *Salix* that are sometimes classed as

trees. It does not attempt to include all of the naturalized trees. The scientific name is followed first by the preferred common name, and then by other local names that are applied to the same species.

LIST OF TREES NATIVE TO ILLINOIS

Conifers

Pinus strobus Linn.	White pine
Pinus echinata Mill. (*Pinus mitis* Michx.)	Shortleaf pine. Yellow pine
Pinus divaricata (Ait.) de C. (*Pinus banksiana* Lamb.)	Jack pine. Scrub pine
Larix laricina (Du Roi) Koch (*Larix americana* Michx.)	Tamarack. Larch
Taxodium distichum (Linn.) Rich.	Bald cypress
Thuja occidentalis Linn.	Arborvitae. White cedar
Juniperus virginana Linn.	Red juniper. Red cedar
Juniperus communis Linn.	Dwarf juniper

Hardwoods

Juglans cinerea Linn.	Butternut. White walnut
Juglans nigra Linn.	Black walnut
Hicoria pecan (Marsh.) Britton (*Carya olivaeformis* Nutt.)	Pecan
Hicoria minima (Marsh.) Britton (*Carya amara* Nutt.)	Bitternut (Hickory). Pig hickory.
Hicoria aquatica (Michx. f.) Britton (*Carya aquatica* Nutt.)	Water hickory
Hicoria ovata (Mill.) Britton (*Carya alba* Nutt.)	Shagbark (Hickory)
Hicoria laciniosa (Michx. f.) Sargent (*Carya sulcata* Nutt.)	Shellbark. Bottom or Big Shellbark
Hicoria alba (Linn.) Britton (*Carya tomentosa* Nutt.)	Mockernut (Hickory). Bullnut. Whiteheart hickory. Hardbark hickory
Hicoria glabra (Mill.) Britton (*Carya microcarpa* Nutt.)	Pignut (Hickory)
Hicoria villosa (Sarg.) Ashe (*Hicoria glabra villosa* Sarg.) (*Hicoria pallida* Ashe)	Pale-leaf hickory
Salix nigra Marsh.	Black willow
Salix wardii Bebb (*Salix longipes* Anderss.)	Ward willow

Salix amygdaloides Anderss.	Almondleaf willow
Salix fluviatilis Nutt. (*Salix longifolia* Muehl.)	Longleaf willow
Salix lucida Muehl.	Glossyleaf willow
Salix discolor Muehl.	Glaucous willow
Salix bebbiana Sarg. (*Salix rostrata* Rich.)	Bebb willow
Populus tremuloides Michx.	Aspen. Quaking asp. Trembling aspen. Poplar
Populus grandidentata Michx.	Largetooth aspen. Poplar. Cottonwood
Populus heterophylla Linn.	Swamp cottonwood
Populus deltoides Marsh. (*Populus monilifera* Ait.)	(Common) Cottonwood
Betula papyrifera Marsh.	Paper birch
Betula nigra Linn.	River birch
Betula lenta Linn.	Sweet birch. Black birch
Ostrya virginiana (Mill.) Koch	Hornbeam. Hop hornbeam. Ironwood
Carpinus caroliniana Walt.	Blue beech. Water beech. Hornbeam. Ironwood
Fagus atropunicea (Marsh.) Sudw. (*Fagus ferruginea* Ait.)	Beech
Quercus alba Linn.	White oak
Quercus minor (Marsh.) Sargent (*Quercus obtusiloba* Michx.) (*Quercus stellata* Wang.)	Post oak. Run oak
Quercus macrocarpa Michx.	Bur oak. Mossycup oak. Overcup oak
Quercus lyrata Walt.	Overcup oak. Bur oak
Quercus acuminata (Michx.) Houda (*Quercus muhlenbergii* Engelm.)	Chinquapin oak. Pin oak. Chestnut oak. Yellow oak
Quercus platanoides (Lam.) Sudw. (*Quercus bicolor* Willd.)	Swamp white oak. Bur oak
Quercus michauxii Nutt.	Cow oak. White oak. Bur oak
Quercus texana Buckl.	Texan oak. Red oak. Black oak. Pin oak. Water oak
Quercus rubra Linn.	Red oak. Black oak
Quercus coccinea Muenchh.	Scarlet oak. Red oak. Black oak
Quercus velutina Lam. (*Quercus tinctoria* Bartr.)	Yellow oak. Black oak

Quercus digitata (Marsh.) Sudw. (*Quercus falcata* Michx.)	Spanish oak. Red oak. Black oak
Quercus palustris Muenchh.	Pin oak. Water oak
Quercus ellipsoidalis Hill	Northern pin oak. Hill's oak. Black oak
Quercus marilandica Muenchh. (*Quercus nigra* of authors)	Blackjack. Jack oak
Quercus imbricaria Michx.	Shingle oak. Laurel oak. Jack oak. Water oak. Pin oak
Quercus leana Nutt.	Lea oak
Quercus phellos Linn.	Willow oak
Quercus pagodaefolia (Ell.) Ashe	Swamp Spanish oak. Red oak. Yellow-bottom oak. Water oak
Ulmus pubescens Walt. (*Ulmus fulva* Michx.)	Slippery elm. Red elm
Ulmus americana Linn.	White elm. American elm. Water elm
Ulmus racemosa Thomas (*Ulmus thomasi* Sarg.)	Cork elm. Rock elm. Hickory elm
Ulmus alata Michx.	Wing elm. Winged elm. Wahoo
Planera aquatica (Walt.) Gmel.	Planer-tree
Celtis occidentalis Linn.	Hackberry
Celtis mississippiensis Bosc	Sugarberry. Hackberry
Morus rubra Linn.	Red mulberry
Toxylon pomiferum Raf. (*Maclura aurantiaca* Nutt.)	Osage orange. Hedge plant. (Widely naturalized)
Magnolia acuminata Linn.	Cucumber-tree
Liriodendron tulipifera Linn.	Tulip-tree. Yellow poplar. Tulip-poplar. Whitewood
Asimina triloba (Linn.) Dunal.	Pawpaw
Sassafras sassafras (Linn.) Karst. (*Sassafras officinale* N. & E.)	Sassafras
Hamamelis virginiana Linn.	Witchhazel. Hazel
Liquidambar styraciflua Linn.	(Red or) Sweet gum. Gum
Platanus occidentalis Linn.	Sycamore. Buttonwood. Buttonball tree
Pyrus coronaria Linn. (*Malus coronaria* Mill.)	Sweet crab. American crab. Wild crab. Crab apple
Pyrus angustifolia Ait. (*Malus angustifolia* Michx.)	Narrowleaf crab

Pyrus ioensis (Wood) Bailey (*Malus ioensis* Britt.)	Iowa crab
Pyrus soulardi Bailey (*Malus soulardi* Britt.)	Soulard crab
Amelanchier canadensis (Linn.) Medic.	Serviceberry. June berry. Shadbush
Crataegus crus-galli Linn.	Cockspur. Red haw. Cockspur haw
Crataegus coccinea Linn.	Scarlet haw. Red haw. White haw
Crataegus tomentosa Linn.	Pear haw. Blackthorn. Hawthorn. Thorn apple
Crataegus cordata (Mill.) Ait.	Washington haw
Crataegus viridis Linn.	Green haw
Crataegus macracantha (Lindl.) Lodd.	Longspine haw
Crataegus mollis (T. & G.) Scheele	Downy haw
Crataegus punctata Jacq.	Dotted haw
Crataegus spp. (Various other species of minor importance)	
Prunus nigra Ait.	Canada plum
Prunus hortulana Bailey	Wild garden plum
Prunus angustifolia Marsh. (*Prunus chicasa* Michx.)	Chickasaw plum. (Probably naturalized)
Prunus pennsylvanica Linn. f.	Wild red cherry
Prunus virginiana Linn. (*Prunus demissa* Walp.)	Choke cherry
Prunus serotina Ehrh.	Black cherry. Wild cherry
Cercis canadensis Linn.	Redbud. Judas tree
Gleditsia triacanthos Linn.	Honey locust
Gleditsia aquatica Marsh. (*Gleditsia monosperma* Walt.)	Water locust
Gymnocladus dioica (Linn.) Koch (*Gymnocladus canadensis* Lam.)	Coffeetree. Coffeebean. Kentucky coffeetree
Robinia pseudacacia Linn.	Locust. Black locust
Xanthoxylum clava-herculis Linn.	Prickly ash
Ptelea trifoliata Linn.	Hoptree. Whahoo.
Ailanthus glandulosa Desf.	Ailanthus. Tree of Heaven. (Ex cult. escaped)
Rhus hirta (Linn.) Sudw. (*Rhus typhina* Linn.)	Staghorn sumach. Sumac
Rhus copalina Linn.	Dwarf sumach
Rhus vernix Linn. (*Rhus venenata* DC.)	Poison sumach

Ilex decidua Walt.	Deciduous holly
Evonymus atropurpureus Jacq.	Waahoo. Burning bush. Arrowwood
Acer saccharum Marsh. (*Acer saccharinum* Wang.)	Sugar maple. Sugartree. Hard maple. Rock maple
Acer saccharum var. *nigrum* (Michx.) Britton. (*Acer dasycarpum* Ehr.)	Black maple
Acer rubrum Linn.	Red maple. Soft maple. Swamp maple
Acer negundo Linn. (*Negundo aceroides* Muench.)	Boxelder. Ash-leaved maple. Negundo maple
Aesculus glabra Willd.	Ohio buckeye
Aesculus octandra Marsh. (*Aesculus flava* Ait.)	Yellow buckeye
Rhamnus caroliniana Walt.	Yellow buckthorn
Tilia americana Linn.	Basswood. Linn. Linden
Tilia heterophylla Vent.	White basswood. Linden
Aralia spinosa Linn.	Angelica-tree. Hercules club
Cornus florida Linn.	(Flowering) Dogwood
Cornus alternifolia Linn.	Blue dogwood. Alternate-leaved dogwood
Nyssa sylvatica Marsh. (*Nyssa multiflora* Wang.)	Blackgum. Sour gum. Tupelo
Nyssa aquatica Linn. (*Nyssa uniflora* Wang.)	Cotton gum. Tupelo
Vaccinium arboreum Marsh.	Tree huckleberry
Bumelia lanuginosa (Michx.) Pers.	Shittimwood
Bumelia lycioides (Linn.) Gaertn. f.	Buckthorn bumelia
Diospyrus virginiana Linn.	Persimmon
Mohrodendron carolinum (Linn.) Britton (*Halesia tetraptera* Ellis)	Silverbell-tree
Fraxinus quadrangulata Michx.	Blue ash
Fraxinus nigra Marsh. (*Fraxinus sambucifolia* Lam.)	Black ash
Fraxinus americana Linn.	White ash
Fraxinus pennsylvanica Marsh. (*Fraxinus pubescens* Lam.)	Red ash
Fraxinus lanceolata Borkh. (*Fraxinus viridis* Michx. f.)	Green ash
Fraxinus profunda Bush.	Pumpkin ash. (Schneck)
Catalpa catalpa (Linn.) Karst.	(Common) Catalpa. Indian bean. Cigar-tree. (Naturalized)

Catalpa speciosa Warder	Hardy catalpa
Viburnum lentago Linn.	Sheepberry. Black haw
Viburnum rufidulum Raf.	Black haw
Viburnum prunifolium Linn.	Nannyberry. Black haw
Foresteria acuminata Poir. (*Adelia acuminata* Michx.)	Foresteria. Swamp privet

Ownership and Taxation of Forest Lands

At least ninety per cent of the Illinois woodlands are owned by farmers, which means that ownership is stable and favors forest management. The proportion is less in some of the southern mining counties, such as Jackson, Perry, and Williamson, where considerable woodland is held by coal companies. There are also a few large bottomland tracts in the hands of lumber companies, but, unlike the mining companies, these owners are only temporarily in possession and expect to sell the land to farmers when it is cleared.

For purposes of taxation land is classified as improved and unimproved, and the assessor places a different value per acre on the improved and unimproved land of each farm. This full valuation is supposed to equal the actual sale value of the land, but in practice often falls below this figure. The assessed value is one-third of the full valuation; the rate of taxation varies considerably in the various counties and townships, but it averages between three and four per cent. Thus the actual tax is about one per cent, or a little more, of the full value. Woodlands are usually classified as unimproved land, although sometimes when fenced and pastured they may be included with the improved. Very little attention is ordinarily paid to the character of the timber on the land unless it happens to be exceptionally good, in which case the land may be valued as high as agricultural land. Scrubby cut-over woodland in rough country is worth about $5 per acre, while better timberlands are valued at $10 to $30 per acre, leaving out of consideration exceptionally good tracts.

On the whole, the taxes levied on Illinois woodlands are not excessive, and have had practically no effect on the time of cutting timber or other features of forest management. Therefore it does not seem advisable to change the system of taxation at present. Eventually a tax based on yield will have to be substituted for the present tax based on the combined value of the land and timber. This change will doubtless come about with the development of forest management on scientific principles and with a general reform of the present taxing system.

Timber Industries

Although Illinois is not primarily a timber-producing state, its forest products are considerable in amount and value. The larger mills and woodworking establishments that use local timber are restricted to the southern part of the state, with the exception of a few that draw their supplies from the Illinois and Mississippi bottoms. Throughout all of the wooded portions, however, a great deal of timber goes into small products such as ties, fuelwood, posts, and other material used on the farm, and it is impossible to get statistics covering all of these items. The consumption of firewood in 1908 is estimated at over two million cords, most of which is cut within the state. The output of lumber is shown in Table VII and that of slack cooperage stock in Table VIII.

The products of greatest importance are rough and finished lumber of all kinds, railroad ties, cooperage stock, boxes, piling, telephone and telegraph poles, handles, wagon stock, and mine timbers, while products of less importance commercially are fuelwood, split hoops, fence posts, charcoal, pulpwood, and edible nuts.

Illinois is exceptionally well provided with transportation facilities both for conveying the rough material to the mill and the finished product to the markets. The large number of navigable streams afford cheap water transportation, while a dense network of railroads provides an outlet for all industries not located directly on a river. The wagon roads throughout the state are numerous and well distributed, but the majority of them are not macadamized or gravelled, and their condition depends on the weather. Good transportation facilities provide means to handle the less valuable products at a profit and tend toward closer utilization of timber.

There is everywhere a good demand for most forest products. The numerous large cities in this and adjoining states afford excellent market facilities, while the local demand is usually great enough to take care of all the lower grades that can be produced. The mining industry requires a constant and large supply of rough timbers, props, small ties, and lumber, while the railroads can more than absorb all of the cross-ties produced. The demand for fuelwood is, on the whole, poor, because soft coal is so cheap and convenient in most parts of the state. Nevertheless, an enterprising manager can nearly always find some good way of disposing of this product. Fence posts are becoming scarce in many places, and nearly always command a ready sale.

The value of standing timber depends on a number of different factors, chief of which are the quality of the material, accessibility of the tract for logging, and distance from the market. Since these are

quite variable, average figures such as are given here are of very general application and not suitable for valuing any particular tract.

White oak is the most expensive wood that is cut to any large extent, and varies in stumpage value from $6 to $30 per thousand, according to grade. The average quality that is standing now is worth about $10. Black oak runs from $3 to $6 a thousand, with red oak, as a rule, somewhat higher, although at times it is classed with the black. Pin oak gives a low grade of lumber, and averages about $4 a thousand in stumpage value, but others of the so-called water oaks, especially swamp Spanish and Texan, produce a better grade, occasionally reaching $15. Elm, hackberry, cottonwood, red gum, maple, and sycamore are generally classed together as "soft-woods" and sold for both lumber and staves, at prices ranging from $1 to $5 a thousand, but averaging about $2. Hickory is worth in the neighborhood of $6 a thousand, but good virgin trees will bring more. Ash of fair quality brings about $7.50 a thousand, but what remains of this species is likely to be of inferior quality. In the southern part of the state prices increase toward the north, where markets improve and where timber grows scarcer, but individual localities sometimes show exceptions to the rule, due to special conditions. In northern Illinois, with the exception of districts along the largest rivers, timber is seldom sold on a stumpage basis, but the actual values are somewhat higher, owing to proximity to big markets.

LUMBER MILLS

Most of the mills which cut rough lumber are of small capacity and run intermittently. They are usually of the portable type, with a traction engine for motive power. This arrangement is very economical, as the engine can be used for other purposes, such as threshing, when the mill is idle. The more permanent small mills which use either water or steam power, and both in some cases, very often are run as adjuncts to grist-mills. Practically all of these mills do a much varied business. They saw logs for other parties at a rate of $4 to $5 per thousand, or they buy the timber, on the stump or in the log, selling the rough lumber locally and shipping the best grades. Small-mill owners seldom buy stumpage at a stated price per thousand, but usually purchase the timber by lot, giving a lump sum for all the timber or all of certain species on a given area. Since the portable-mill owners have the advantage of being able to set up on the area to be cut, and thus save a great deal in the expense of hauling logs to the mill, they do a much more general business than the small permanent mills, which confine themselves largely to custom sawing.

The prices paid for timber are generally a little lower than that given by the large mills, as they usually deal in lower grades, often cutting over an area after the large-mill owner has culled it of its best timber.

There is a great deal of waste connected with small mills, due to the rough methods, wide saw kerf, lack of alignment in the machinery, and unskillful sawyers. This, however, is offset to some extent by the fact that they can utilize certain classes of lumber, such as waney-edged and cull, that the big mill can not dispose of through the ordinary channels of trade. Many of the small mills cut railroad ties. This is especially true of portables, which can afford to cut over land which has been culled of its best saw-timber. Tie dealers prefer to buy from mills sawing ties exclusively, as other mills are apt to use the best part of the logs for lumber and to cut the worst logs or worst part of the logs into ties, thus lowering the general grade.

The lumber industry of the future will undoubtedly be entirely in the hands of the small-mill owners. With the prices of lumber constantly rising, they will find it to their advantage to buy improved machinery and to use more care in sawing. By doing this the chief disadvantage of the use of small mills is removed.

The large mills are near the end of their supplies, and ten years from now not one will be cutting native timber. They are now confined to points along the large rivers, where they can draw on extensive territory and transport their logs cheaply by raft or barge from the few remaining large bodies of virgin timber, which are principally confined to the bottoms. Practically all these mills are preparing to move in a few years. The large mills with a yearly output of over five hundred thousand feet used about fifteen million four hundred and fifty thousand board feet during 1909, in the twenty-six counties covered, while the small mills cut approximately sixty-three million two hundred and fifty thousand board feet. The average output of the larger mills was nine hundred and sixty-five thousand board feet, and of the smaller, one hundred and forty-three thousand board feet.

The large mills buy the timber outright over large areas of land, purchasing either land and timber together, or only the stumpage. The closest utilization is found where the same company handles both "softwoods" and "hardwoods." Softwoods, as the term is commonly used, includes those woods suitable for staves and veneer boxes, such as elm, maple, gum, and cottonwood, while hardwoods comprise the other species, chiefly oak and hickory. These are all hardwoods, technically speaking, but the differentiation of terms is clear, since real softwoods, or conifers, are not of usual occurrence. The only conifer used in the lumber industry in this state is cypress.

A very good example of close utilization is furnished by the methods of operation of a big firm working on the Illinois River. This com-

pany cuts the land practically clear, using all timber down to five or six inches in diameter, including big limbs which are suitable for staves or heading. The hardwoods are cut into various kinds of lumber and handles, while the softwoods are cut into staves, heading, and hoops. Durable species are made into fence posts, while the tops and other slash are cut into cordwood and sold in the cities. They are enabled to use hollow-butted logs and small wood, since they transport all their timber to the mill on barges. Where rafts are used, this is not possible, but the saving in waste would be likely to more than make up for the higher cost of transportation by barge. Some large mills cut both hardwoods and softwoods into lumber.

In another locality the hardwoods and all softwoods below a certain diameter limit are owned by one company, and the softwoods above this diameter by another. In this case the hardwoods were barged, but the softwoods were rafted to the mills. The small hardwoods and softwoods were later cut into ties or wagon stock by small portable mills. While this system should result in close utilization, the lack of good organization caused considerable waste. Several cuttings over one area resulted in logs and merchantable trees being left in the woods, and the timber was not used for the highest possible grade of products. Then, too, there was considerable loss of time and labor. Rafting meant the leaving of many unfloatable logs, and some which floated at first sunk before they reached their destination. The market for cordwood was not good, and no attempt was made to utilize such material. Tops fit for ties were left because hard to cut.

Large mills seldom care about the condition in which they leave the forest, since they either do not own the land or are not permanent owners. After getting their profit from the timber, they expect to sell the cut-over land for what it will bring.

Fortunately, a greater part of the land controlled by the mill owners is not permanent forest land, and is either now available for agricultural purposes or will be in the future when improvements for controlling and preventing floods are completed. Although there are areas where the curtailment of the present cut would allow of a second profitable operation in ten to twenty years, most of the mills can not wait so long, lacking a sufficient supply to tide them over the interval. In this case, forest management of such lands is impossible, and all efforts in the line of forestry should be directed to obtaining closer utilization.

The amount of timber sawed during 1909 in the counties covered in this investigation, is shown in Table VII. Material brought in from other states is excluded. These figures are compiled from reports secured by the Forest Service in cooperation with the Bureau of the Census.

TABLE VII.—PRODUCTION OF LUMBER BY COUNTIES, ILLINOIS, 1909.

Thousand Feet—Board Measure.

County	Cypress	Oaks	Maple	Tulip-poplar	Red gum	Beech	Birch	Elm	Cottonwood	Ash	Hickory	Tupelo	Walnut	Sycamore	Cherry	Total	Number of mills
Southern Illinois:																	
Alexander	379	1,821	89	261	543	454	..	199	140	40	222	115	5	223	..	4,491	16
Franklin	..	2,943	60	100	41	...	1	43	10	4	135	..	3	11	1	3,352	21
Gallatin	325	3,620	55	102	795	..	..	53	30	270	1,138	..	22	25	..	6,435	9
Hamilton	10	1,632	94	10	654	..	29	111	19	19	97	..	8	96	2	2,781	24
Hardin	..	390	..	5	35	..	..	25	..	..	15	..	..	5	..	475	3
Jackson	..	2,830	35	33	260	21	2	40	10	27	235	..	..	46	..	3,539	20
Jefferson	..	3,420	147	..	35	5	22	117	..	8	205	..	16	58	..	4,033	22
Johnson	70	2,575	182	121	320	..	5	302	..	32	171	28	26	113	..	3,945	18
Lawrence	..	700	155	..	91	..	1	190	8	58	10	..	1	78	..	1,292	4
Massac	643	2,614	41	192	704	..	..	156	14	26	266	80	1	57	..	4,794	24
Perry	..	2,477	46	..	51	..	13	34	..	9	88	..	2	28	3	2,751	25
Pope	148	2,066	70	282	258	..	..	136	25	7	143	25	1	65	..	3,226	15
Pulaski	147	2,796	300	112	975	120	..	780	1	177	525	285	51	538	..	6,807	17
Randolph	..	1,366	8	15	..	..	2	111	17	14	125	..	27	65	6	1,756	21
St. Clair	..	2,105	93	5	28	..	3	99	56	72	53	..	13	84	14	2,625	38
Saline	190	1,630	20	42	567	20	5	52	2	8	62	..	1	82	1	2,682	13
Union	271	5,231	43	324	370	442	..	261	1	119	502	5	24	94	..	7,687	33
Wabash-Edwards	..	1,452	57	40	65	..	20	85	..	18	188	..	6	4	4	1,939	16
Washington	..	2,336	133	..	..	..	4	134	20	38	221	..	31	117	6	3,040	43
White	..	2,515	65	10	105	..	1	206	..	13	155	..	..	18	..	3,088	14
Williamson	..	3,204	222	42	135	40	25	119	..	42	185	..	2	36	1	4,053	19
Total	2,183	49,723	1,915	1,696	6,032	1,102	133	3,253	353	1,001	4,741	538	240	1,843	38	74,791	415
Northern Illinois:																	
Calhoun and Pike	..	2,904	151	..	5	..	123	362	123	17	64	..	34	117	2	3,902	27

CROSS-TIES

The business of supplying the railroads with cross-ties is of importance, but mainly in the southern part of the state. The establishment of treating-plants has made possible the utilization of red oak, beech, and "softwoods." During the year 1909, the output of ties from the southern region amounted to approximately four hundred and fifty thousand, the great majority of which were destined for preservative treatment. This year the market for ties was very poor, and ordinarily the production would be much higher. More than half are obtained from the bottomland type, and are made from timber that is either defective or a little too small to make lumber, box-boards, or staves economically.

The price paid for ties delivered at the railroad varies somewhat with the location of the station, the specifications, and the rigidity of inspection. The following were average prices for southern Illinois early in the year 1910: white oak, forty cents; red oak, thirty cents; "softwoods," twenty-five cents. Beech is sometimes classed with the gum, elm, sycamore, and other so-called "softwoods," but is often kept separate, and commands a slightly higher price. Its hardness makes it resist the wearing of the rail longer than the softer woods.

The stumpage value of ties is very low—usually almost nothing for softwoods, and about six to ten cents for oak. To a certain extent this condition is due to temporary dullness in the market, but the principal cause is the attitude of the owners themselves. They are generally farmers who are satisfied to practically give their timber away in order to get paid for the labor of felling the trees, hewing the ties, and hauling them to market. Very often the actual wages earned in this way are smaller than the same man would hire out for, because he does not usually figure expenses, but is content if the sum received for his ties seems like a fair profit. As long as so many people are glad to dispose of ties on this basis, stumpage values are bound to remain near the zero mark.

There are two sources of waste in tie-making as now carried on. First, many trees are cut just at the time when they are putting on the maximum amount of valuable wood. Straight thrifty trees large enough to make several ties are very easy to work up, but it is much more profitable to allow them to reach larger size before cutting. When small trees are used for ties they should be thinned from overcrowded stands and should be of the less desirable species. Trees of this class are not likely to be so easy to work up, and the woodsman lets them stand. Second, a great deal of wood is wasted in hewing ties, especially if the timber is knotty. Nevertheless, about eighty per cent of the ties are hewed rather than sawed.

To make and deliver a hewed tie costs about three cents less than if it were sawed, and inspection is much less rigid, so that a slightly undersized or defective tie will be accepted if hewed, when it would be rejected if sawed. Most timber will, however, yield about one-third more in sawed ties. The only exception is the case of a clear tree with a moderate crook. In this case the curve of the grain would be followed by the hewer, while the saw would cut straight through and waste a big slab. On the whole, however, there is much less waste in sawing than in hewing. Sometimes props and cordwood are made from the portions of the tree that can not be made into ties, and this saves a great deal of wood which would otherwise be wasted.

MINE TIMBERS

The mining of bituminous coal is an industry of great importance in Illinois, and one which creates a large demand for timber, especially of low grade and small size. The small timber used for mining purposes consists chiefly of props, caps, and mine-ties. Props are from four and one-half to ten feet long, depending on the thickness of the coal seam, and from three to six inches across at the small end, either split or round. Most of the props are used in galleries which will be worked out in the course of six months or a year, and consequently durability is not essential, since almost any wood will last this length of time, if strong enough to resist the mechanical strain. Therefore, practically all woods are used for props, although oak is preferred and black oak is used to a greater extent than any other wood. The cost averages slightly less than one cent per linear foot at the southern mines, and slightly more at the northern, where there is practically no local supply.

Caps are small pieces usually about an inch thick, six inches wide, and sixteen inches long, which are used to wedge the props in place. Sometimes they are split, but board ends, slabs, and other sawmill waste is used. The cost is from $4 to $7 per thousand, delivered.

Mine-ties vary in size from three to five and one-half feet in length and from three to five inches in thickness. They are either split or round sticks squared off on two sides, and consist chiefly of oak, although many other woods are used where permanence is not required. The cost at the mine is from three and one-half to ten cents each.

There is also a considerable amount of larger timber used in more permanent construction both inside and outside of the mines. This includes entry props and collars, and lumber used in building tipples. Higher grades are required for this work, and often the local supply is not able to meet the requirements. White oak and yellow pine are shipped in from the South for these purposes.

The amount of timber required varies with the method of mining and with geologic conditions. The number of props used is, perhaps, the most variable factor, and depends largely on the quality of the rock covering which forms the roof of the coal seam. On the average, in southern Illinois one prop is used for every ten tons of coal mined. Taking all classes of timber used within the mine, about one-fifth of a cubic foot is required per ton of coal produced, and the cost is about one and one-half cents per ton. These averages are based on figures obtained from Illinois mines chiefly in the southern part of the mining region. Based on the total Illinois production of coal in 1909, the annual consumption, excluding timber used in tipple construction and for other purposes outside of the mine, would amount to nine million eight hundred and thirty-three thousand cubic feet, with a value of over $737,000.

This large amount of timber is supplied from several sources. The mines south of the latitude of St. Louis get most of their timber from the farmers of their own localities, while those farther north, where woodland is less abundant, must ship in the greater part of their supply by rail. A great many props are cut in the southern bottomlands and shipped north, and much mine timber is also brought in from Kentucky and other states to the south. Very few mines draw any considerable portion of their supply from their own woodlands.

It would be of great advantage to mining companies that are located in a section which includes land adapted to growing timber, to own and manage enough woodland to supply the greater part of their present and future needs. They will then be independent of the general market, and need not fear a future shortage and high prices. Some of the southern mines are now in a position to raise at least a part of their supply. Approximately one thousand and seven hundred acres under proper management should furnish enough timber continuously for an annual output of five hundred thousand tons, but without systematic management a much greater acreage would be required. If a company wishes to handle its woodland on a conservative basis, the first step is to secure a competent woods-foreman in place of the contractors now usually depended upon to provide timber. His efficiency should be rated not only upon his ability to get timber to the mine cheaply, but also upon the condition in which the forest is left. He should superintend all cuttings, and see that no timber is wasted in tops or large limbs. During the danger seasons the protection of the tract from fire should be his chief duty. Silvicultural methods of growing mine timbers will be discussed in the chapter on forest management.

It would also pay mine operators to investigate the proposition of treating with chemical preservatives timber that is to be used in permanent work. By such treatment the less durable woods will last as long as the best white oak, and a large saving can be made in the amount of timber used and in the cost of its replacement.

SLACK COOPERAGE

The slack cooperage industry draws heavily upon the supply of bottomland timber in both the southern and northern parts of the state. All of the common bottomland "softwoods" are readily made into slack barrels with the exception of black gum and honey locust. Red gum and elm are the most used for this purpose. The trees are usually cut to a diameter limit of twelve inches at the stump by the southern stave manufacturers; but in the northern part of the state, where timber is scarcer, they are cut to a smaller limit, sometimes as low as eight inches. The stumpage value of stave timber per thousand board feet is $1.50 to $2.50 on the southern bottoms, and $2.50 to $3.50 in northern Illinois.

Table VIII shows the production of slack cooperage from native timber in the year 1908, as obtained by the Forest Service in cooperation with the Bureau of the Census. The figures for 1909 will probably show a considerable reduction.

TABLE VIII.—PRODUCTION OF SLACK COOPERAGE IN ILLINOIS, 1908.

Staves—Thousands	Red gum	Elm	Beech	Maple	Ash
Northern Illinois	19,736	14,741	700	5,599	750
Southern Illinois	6,575	4,914	233	1,866	283
Barrel Heading—Thousands of sets	671	20	..	470	44

Staves—Thousands	Oak	Sycamore	Willow	Birch	Cotton-wood	Pecan
Northern Illinois	200	2,816	780	263	2,303	..
Southern Illinois	67	939	260	88	768	..
Barrel Heading—Thousands of sets	10	30	..	20	33	8

HOOP-POLES

An industry that is carried on at times, and which offers some opportunity to utilize small material on cut-over lands soon to be cleared for agriculture, is the making of split hoops. The market for these hoops varies, but they can sometimes be handled at a profit when the demand can not be met by machine-made hoops. Young hickory trees from one-half to four inches in diameter and six and one-half feet long are used. It is not recommended, however, that good young growth of hickory be used for this purpose, especially where it is on land that is to be held permanently in forest, unless it happens to be taken out in thinning a stand that is too dense.

BOX MATERIAL

The fruit and canning industries of southern Illinois create a demand for boxes and crates that is met to a certain extent by local factories. Gum, maple, tulip-poplar, and cottonwood are the chief woods in use. Tupelo and cottonwood are used especially for egg-crates. Few factories obtain their entire supply of raw material from within the state, and many ship in one-half or more from Kentucky or Missouri.

CHARCOAL

In the southern part of the state there are quite a few charcoal plants, usually equipped with ordinary brick kilns. Softwoods comprise about three-quarters of the timber used in this way. The industry is very advantageous in providing a market for wood that would otherwise be wasted in clearing up the bottomlands for agriculture. The usual price paid for mixed wood is from $1.50 to $2 per cord.

FENCE POSTS

It is impossible to give any right idea of the size of the fence-post industry. The individual farmer generally cuts his own posts if he has any suitable wood; if not, he buys them in the neighborhood. The principal trees used are durable species such as catalpa, walnut, cherry, mulberry, juniper, and the oaks, especially white, post, bur, and black oaks; while the less durable woods are occasionally used where the better class is not available. Many cedar posts from the northern states are also being imported, but the supply is running short and the price increasing. Cement posts are beginning to compete with wood, but it is doubtful whether they will ever seriously affect the market, except perhaps in the prairie region, on account of their cost.

The question of planting timber for posts in nonwooded districts has attracted much attention, and is treated in a special circular of the Forest Service.*

Improvement should be made in using inferior species and defective trees as much as possible, rather than to cut up good trees, as is now the custom. The use of preservative treatment† will put the less durable woods on a par with the better species, and avoid much waste of material better suited for other and more valuable purposes.

THE NUT INDUSTRY

Many farmers make small sums by collecting and selling pecan and hickory nuts. There is no reason why this industry should not be enlarged by proper treatment of the natural stand along the rivers, such as the Mississippi, Ohio, Wabash, and Illinois, where pecans form a considerable proportion of the stand and the yield of nuts in good years is large. On the cut-over areas on the bottoms of these rivers there are generally a great number of small pecan trees left after lumbering, and open groves of trees where the pecans form as high as ninety per cent of the stand are not uncommon.

On the Ohio-Wabash bottoms certain acres gave in good years a yield worth $12. The prices obtained for the nuts were ninety cents to $1 a bushel for hickory nuts and twelve and one-half cents a pound for pecans. On the Mississippi an owner gave the following figures for his pecan grove: The trees yielded one to four bushels of nuts per tree, worth $3.50 to $4 a bushel. The yield from two acres of trees and some scattered trees about the farm amounted to about seventy-five bushels in good years. Another example shows the yield from a tract of about twenty acres which had been cleared of all trees except the pecans. In 1902 the owner netted $90 from the sale of the nuts at six to six and one-half cents per pound, after allowing one-half of the nuts as compensation for the pickers. In 1903 the crop was poor, but the owner netted $48, at $3 per bushel. Taking the average of these two crops, the net income would be $69, or $3.45 per acre. This land cost less than $25 an acre, so that this income represents more than fourteen per cent on the investment. Of course, from these instances nothing but general inferences can be drawn, but it seems an industry that would bear closer investigation and more development in connection with forest management. The yield per tree varies with age and form, a mature tree with spreading crown being most prolific.

*Circular 69, "Fence Post Trees."

†This subject has been fully treated in the U. S. Department of Agriculture's Farmers' Bulletin 387, "The Preservative Treatment of Farm Timbers."

To obtain this form, the trees must stand in rather open groves. This will decrease the lumber value of the tree, but the land may be used for pasture. Should it be necessary later to clear the land for other crops, the trees will still yield a considerable profit in lumber, as pecan can be used in short bolts for carriage stock. The following sample plot gives the number of trees per acre in a pecan grove in Gallatin County. By cutting out the other species this grove could be considerably improved.

Diameter breasthigh	Pecan	Elm	Ash	Hackberry
6	4	..	4	4
8	4	..	..	4
10	4	..	..	..
12	8	4	..	..
14	8	..	4	..
16	4	..	..	..
18	4	..	..	..
20	4	..	..	..
Total.....	40	4	8	8
Per cent.....	66.7	6.7	13.3	13.3

Butternuts, hickories, and walnuts are now sold to a very small extent, but they as well as the pecans should be a considerable source of income. The cost of gathering the nuts is small, as it can be done by children.

Forest Management

THE SUITABILITY OF LAND FOR FORESTRY

The first step in forest management is to determine the class of land that is suitable for the purpose. This depends largely on what the soil will yield in timber compared with what it will produce in ordinary agricultural crops. The absolute cash value of the land is not always a criterion of its value for a specific use. Thus land may be profitably used in growing timber for home consumption that would be too valuable to permit of raising timber for the general market. There are few farms on which from ten to twelve per cent of the acreage could not well be set aside as a permanent woodlot. As a rule the land that is least fertile and the hardest to cultivate should be used for this purpose.

The bottomlands of Illinois are rapidly being converted from forest to agricultural lands by drainage and the construction of levees to

prevent overflow. Many projects of this nature are now in course of execution. Only those portions that are most difficult of drainage are suitable for reservation as permanent farm woodlots. Although eventually all the overflow lands will doubtless be reclaimed, extensive areas will probably remain unimproved for periods ranging from ten to forty years, and in the meantime should be made to produce as much timber as possible.

The hill type of forest, since it grows on rough land, will, to a large extent, be permanent. Steep slopes may not safely be cleared because of the danger of erosion and the consequent destruction of the value of the land for any purpose. The higher ridges are of no value for raising agricultural crops, and would be better left in timber. The chief perplexity that arises in connection with the determination of the best use of this class of land is whether or not it should be devoted primarily to stock-raising. It is not profitable to try to combine permanent timber production with heavy grazing. However, it is entirely possible to graze a limited number of animals on forest land without injury to the older trees, and to provide for the renewal of the forest by keeping the stock off from sections that are being restocked with young growth, until the trees are large enough to escape injury. This will probably prove to be the most satisfactory policy in regard to most of the hill forest land. The higher portions of this region are the only parts of Illinois that contain absolute forest land in bodies more extensive than ordinary farm woodlots.

In the uplands of the lower Illinoisan glaciation, the black oak-hickory type on broken land is most suitable for permanent woodlots. The post-oak flats are not suited to growing timber of good quality, and at the same time the rate of growth is very slow. Land of this class is nevertheless considered worth from $20 to $40—a price far above its value for timber production. Although the soil is not naturally fertile, experience has shown that in most cases it will respond to proper treatment and in a few years will produce much more in agricultural crops than in timber. This type of land, therefore, should be cleared as fast as needed, and the woodlots confined to the portions with poorest drainage and to the black oak-hickory land, where this is available.

Practically all of the northern Illinois upland woodlots should remain in forest, since the clearing off of timber has already gone too far. It is especially important to maintain a forest cover on steep slopes that are likely to wash out, and on very sandy soils that are likely to blow. Examples of bad erosion following the clearing of slopes that should have remained in timber are found in western Carroll County south of Savanna. Unwise clearing ruins land both for agriculture and timber production.

GENERAL METHODS

When a tract of forest land has been set aside permanently or temporarily for the growing of timber, the next step is to provide for the handling of the forest in such a way as to produce the greatest returns. Forest protection is of course necessary, and a discussion of this subject is given later. Where cutting is warranted, correct methods must be adopted. In some instances planting may be necessary. To better understand what methods of cutting are desirable, it is well to note the effect of the methods that are commonly used.

The ordinary logging operation consists in taking out all of the best trees of whatever class of timber is wanted. This may injure the productive capacity of the forest in four ways. First, the rate of growth of the stand as a whole is likely to be reduced, since the most easily utilized trees are usually the thrifty rapid-growing individuals, and the tendency is to leave unhealthy trees. Second, the quality of the future timber is damaged, since defective trees are left to grow, and the irregular spacing fosters uneven development of the better trees and causes many to die from isolation. Third, the composition of the stand often deteriorates through the leaving of the least desirable species to occupy the ground. Fourth, the soil is too suddenly exposed to wind and sun, so that it dries out and comes up to weeds and grass instead of trees. Fortunately, all of these unfavorable conditions do not always prevail, as sometimes the demands of utilization more closely approximate the requirements of the stand, or the reproductive capacity of the best trees may be so good that the composition does not materially change. But in the majority of cases throughout Illinois the larger timber has been cut so closely and with so little care for the future, that a great deal of improvement work will be necessary in order to fully restore the productive capacity of the woodland.

Mature Stands.—Since bodies of mature timber are scarce in Illinois, it is all the more important that they be handled carefully. Many evils may be avoided by cutting the mature timber properly. If it is practicable from a financial standpoint, and if the tract is accessible, so that logging expenses will not be much increased, it is best to remove the mature timber in three or more cuttings five or six years apart. The first cutting in such a system includes small groups of mature timber throughout the entire forest. The surrounding trees supply seed to these openings, and young growth is soon established. Then the groups are enlarged by a second cutting, and finally merged by one or several succeeding cuttings, allowing intervals between cuttings long enough for reproduction to take place in the openings. By this method the soil is protected from exposure, and if there are trees too small to be cut profitably, these are not isolated too suddenly.

If circumstances make it necessary to cut all the mature timber at once, small groups of seed trees should be allowed to stand until reproduction is established. An average of five or six good seed-bearing individuals per acre should be sufficient for the purpose. By leaving them in small groups the trees are protected from wind, and they may be removed with a minimum of injury to the young growth when no longer needed for seed.

The practice of these methods necessarily increases the cost of logging. The extra care on the part of the choppers in protecting young growth, the reduction in the amount of timber taken at a single cutting, the cost of marking the trees to be cut, and sometimes other incidental expenses, reduce the immediate profit. But these expenditures are small compared with the net returns that result. These returns are represented by the reduction in the time required to secure the next crop and the greatly increased value of the timber.

Cut-over Stands.—The first step in the management of cut-over woodland is to remove the veterans that have been left because of their defects, usually spreading trees that take up a great deal of room and yield little or no wood of value. In case these should be of a desirable species, and reproduction of that species scanty, they may be left until they have produced one or two good crops of seed.

The next step is to improve the second growth, for on this the future stand depends. It may be in dense thickets, in a scattering open stand, or in irregular groups. The denser stands should be thinned, removing the least promising trees in order to stimulate the growth of the better individuals of the more valuable species. Trees that show signs of becoming overtopped or of disease, badly formed trees, and those of the undesirable species, should be cut. Other things being equal, seedlings should be left rather than sprouts if saw-timber is the object. Care must be taken not to make openings large enough to encourage the growth of weeds or shrubs, or to permit the soil to dry out from exposure to wind and sun. Where the density is not sufficient to admit of thinning, improvement measures must be postponed until the density is increased with age, unless planting is resorted to. If the young growth is very scanty and there is no prospect of further natural reproduction from neighboring trees, it is necessary to plant in order to establish a productive forest within a reasonable length of time.

Thinning operations in small timber are often limited by the lack of market for the product. Frequently this can be utilized as mine-props, and sometimes as fuelwood. Where the sale of the material will pay for the operation, there should be no hesitation about making thinnings, and it is often advisable to make them at a present loss for the sake of increasing the ultimate value of the stand.

SPECIAL OBJECTS

The general silvicultural methods that have been outlined must be modified in practice to meet specific conditions. An important influence on management is the class of timber to be raised. This depends upon the ownership of the land and upon market conditions. If the owner needs a certain class of timber for his own use—as posts for the farmer or props for the mine operator—he will find it advantageous to grow it on his own woodland and have his own supply close at hand and independent of the market. Other owners of woodland, who use none or only a part of their timber product, must grow material for which there is a good general market.

Farm Timbers.—Under this head are included fence posts and timber for all kinds of rough construction work on the farm, such as should come from the woodlot. Since it is seldom necessary or desirable to cut much timber at one time, the mature and inferior trees may be selected and cut as they are needed, constantly improving the stand and opening it up for reproduction where desirable; and each tree can be selected for cutting with reference to the good of the forest as well as to the use to which it will be put.

Cross-ties.—The tie market affords a convenient means of disposing of surplus wood from farm woodlots, and in this case no special form of management is necessary. The ties may be the product of a thinning of an overcrowded stand, or may be made from that portion of a final cutting which can not be more profitably used in other ways. In some localities, as in the rougher parts of the Ozark Hills, cross-ties may be the chief object of management, since here the local demand for timber is less in proportion to the amount of absolute forest land. The poorer situations with abundant black oak are especially suitable for the purpose. Since a shorter rotation is possible than if saw-timber were desired, a clear-cutting system with sprout reproduction is recommended. Sprouts grow more rapidly in youth than seedlings, and will produce timber of tie size in less time. To secure the best sprouts, felling should be done in the winter season and the stumps cut low and clean. Since eventually the sprouting capacity of the stumps is exhausted, provision must be made for the gradual renewal of the stand with seedling trees. This is done by leaving a few to stand through a second rotation, during which time they will partially seed the area. Not as many trees need be left as in the ordinary clear-cutting system with seedling reproduction. The stand should be kept more heavily thinned than if clear saw-timber were the object, and incidentally the trees will become more wind-firm, and those left for seed may be distributed singly, where they will do the most good, instead of in groups. Two or three per acre should be enough.

Mine-props.—Mine-props will probably be produced chiefly from the thinning of stands that are intended primarily for ties or saw-timber. Where land is owned by mining companies, however, props may be the principal object of management. The same sprout system as suggested for tie production is most suitable, but with a still shorter rotation. The reserves left for seedling reproduction, after they have served this purpose, may be utilized for larger mine timbers.

Box and Cooperage Timber.—Since for these purposes timber of good size is desired, the general group system should be used, as if for the production of ordinary saw-timber. Those species which are rapid-growing and at the same time adapted to package-making should be favored in the cuttings. The bottomland types are especially well suited to the production of this class of timber.

FOREST TYPES

Special treatment is required, too, with each general forest type, particularly as to what species should be favored. One species may be discriminated against in favor of another by cutting a larger proportion of it when thinning the stand, and by eliminating seed trees. The same result is accomplished by using a diameter limit and cutting the undesirable species to a lower diameter. Of course, where the most valuable kinds do not grow, the next best must be favored.

Southern Bottomlands.—The probability that land of this type will be cleared in a comparatively short time prohibits any scheme of management involving reproduction of the forest except on permanent woodlots. However, if the present cutting operations were restricted to the larger trees, and the best of the young trees were left to grow, the resulting stand would be very valuable in from fifteen to twenty-five years. These stands should be left where it is probable that the land will not be in demand for farming before such a period has elapsed. The trees that are now six to sixteen inches in diameter are making their best development, and the additional light given them by taking out the larger trees would stimulate them to a very rapid growth. Stands that have been cut more closely than is advisable, with a second crop in view, may yield in some cases a second cutting of value. Such stands may be improved by thinning, if the small material taken out can be utilized. Young hickory, of which there is a great deal in some places, may sometimes be handled for hoop-poles with profit.

Most of the bottomland species are valuable for forest management because of their rapid growth and good quality. In general, the trees to be preferred are red gum, swamp Spanish, pin, and white oaks, elm, cottonwood, hickory, and black walnut. Many others of less wide distribution may be fostered in the localities where they grow.

Upland Hill Type.—The hill forests include a great deal of woodland that should be handled on a permanent basis for rough lumber, farm timbers, cross-ties, and mine-props. In many cases the stand is so depleted that any cutting must be deferred until it has grown denser. Fire is the most serious obstacle to forestry in this type.

In general, the following species should be favored on the better situations, such as lower slopes: red and white oaks, tulip-poplar, hickory, ash, and black walnut. Where the slow-growing beech can be replaced by any of these trees, especially tulip-poplar, it should be done. Other less abundant species, such as cucumber and black cherry, are valuable where they occur. On poorer situations, black oaks, hickory, and black locust are the trees to be preferred.

Upland Plain Type.—In the oak-hickory forests it is well to preserve all three of the principal species: white oak, black oak, and hickory. Unless the proportion of white oak is high, it will usually be advisable to favor the increase of this tree. In this case hogs must be kept out during seed periods, since they prefer the sweet white oak acorns to those of the black oak.

The post-oak type must be managed for small material such as fence posts preferably under a clear-cutting system with sprout reproduction. The blackjack must be cleaned out as far as possible, in favor of post and shingle oaks.

Early Wisconsin Terminal Moraine.—The management of the forests on the Wisconsin terminal moraine should, in general, follow the rules laid down for the southern upland forests. The chief points to be emphasized are the removal of the overmature scattered trees, the restriction of grazing, and the attainment and preservation of a dense forest cover on steep slopes. Where beech occurs it should be discriminated against as much as possible without making too large openings.

The oak openings should be protected from grazing, and where shingle oak forms a large part of the mixture, care should be taken in opening the stand, as there is great danger of this species dying from isolation and lack of sufficient shade. Planting may have to be done where the steep hillsides have been denuded, especially where erosion is taking place.

Northern Illinois Types.—The same general plan of management applies to the northern as to the southern forests. The bottoms will hardly be managed for even a second cut, except outside the levees or in places where good drainage is impossible. In such situations pin oak may be managed for cordwood or ties by the clear-cutting method with leaving of seed trees. Cottonwood for pulpwood and lumber, and elm for lumber and staves, may be managed on the same system.

Maple and willow will respond well to a system of reproduction by sprouts.

The upland forests are mainly woodlots, and should be managed by the group selection system. The steep slopes and many stands now in "brush" will have to be handled very carefully, fully protected from fire and grazing, and given many improvement thinnings. Many pastured lots will have to be planted to bring them to a proper state of density and to insure a good composition. Besides the oaks and hickories, it will be well to discriminate in favor of walnut, cherry, and basswood as far as possible. The small groups of aspen that are found far north are only a temporary type and will be naturally superseded by better and more tolerant species. This process may be anticipated by planting if desired.

Sand Lands.—In the sand plains and dunes of northern Illinois the whole effort should be directed toward holding the soil and improving the condition of the stands. These woodlands must be viewed as protection forests, and no cuttings should be allowed that will in any way tend toward the deterioration or opening up of the stands.

Where the present forest is fairly dense and the trees average over twelve inches in diameter breasthigh a light selection-cutting is allowable, but great care must be taken to keep the crown cover dense enough to prevent the drying out of the ground. Other cuttings in younger stands must be confined to cleanings and improvement thinnings. The so-called "scrub" growth requires careful treatment of this kind and should be handled as intensively as financial considerations will permit. The red and black oak should in all cases be favored rather than the blackjack. The inferior species may be handled on a short rotation and used for firewood, but the young trees of the better species should in all cases be allowed to grow to a larger size, at least until they are suitable for ties. This will gradually change the composition of the stand and increase the number of the better species. In cases where the stand is all of one species, such as blackjack, which never grows to any great size, the cuttings should be in strips in a direction at right angles to the prevailing wind. These strips should not be over twenty feet wide and should alternate with a strip of uncut woodland of equal width. The stand may be much improved if these strips are planted with bur, red, or black oak acorns.

The greatest need of this type of forest is protection from fire and grazing. Very light grazing may be permitted among the older stands, but should be avoided if possible. Fires should be kept out at all costs.

Over a large part of the sand lands there is now no forest growth, and steps should be taken to remedy this condition both for the pro-

tection of the soil and to make use of land that at present is unproductive. Black locust has been used very successfully, and is to be recommended in localities which are moderately free from attacks of the locust-borer. Where the supply of moisture in the subsoil is good, cottonwood or North Carolina poplar may also be suitable for planting on these lands.

PLANTING.

The problem of establishing woodlots by forest planting was not investigated, since this field has been covered for central and northern Illinois by a previous publication.* However, it is sometimes desirable to resort to planting in the management of timbered lands where natural reproduction can not be successfully obtained or where it is insufficient in quantity or quality. In such cases it is most important that the species selected for artificial propagation be suited to the soil and moisture conditions. In general, the trees listed as most valuable for management in the different types will also be those which should be planted. Directions for planting any of these trees may be obtained by applying to the Forest Service, Washington, D. C. There is great need for further experimental work in forest-planting of native and introduced species in Illinois.

GROWTH FIGURES.

To get accurate figures on the rate of growth of trees requires a more extensive and lengthy study than was practicable in view of the

TABLE IX.—GROWTH OF SWAMP SPANISH OAK (QUERCUS PAGODAEFOLIA), ILLINOIS

Age Years	Dominant Trees		Intermediate Trees		Suppressed Trees	
	Diameter breasthigh Inches	Height Feet	Diameter breasthigh Inches	Height Feet	Diameter breasthigh Inches	Height Feet
10	1.3	13	1.0	13	0.7	10
20	3.4	26	2.4	25	1.9	20
30	5.7	38	4.0	36	3.1	30
40	8.0	49	5.8	47	4.3	40
50	10.4	60	7.6	58	5.6	48
60	12.8	70	9.7	68	7.0	55
70	15.5	80	12.3	77	8.5	62
80	18.3	90	15.1	87	10.0	69
90	21.1	98	18.2	95	11.7	75
100	24.0	105	21.2	103	13.5	80
110	27.2	110	24.1	107	15.4	84
120	30.3	115	26.9	109	17.3	88

Based on sectional age counts and decade measurements of 44 trees, the stu mps averaging 2.3 feet high, and ranging in age from 54 to 240 years. Measured in Wabash County, Illinois.

* Forest Service Circular 81, Forest Planting in Illinois.

TABLE X.—GROWTH OF SWAMP SPANISH OAK. (Q. PAGODAEFOLIA), ILLINOIS.

Time required to grow to a specified diameter breasthigh.

Diameter breasthigh Inches	Dominant trees Years	Intermediate trees Years	Suppressed trees Years
10	47	61	80
11	52	65	85
12	57	69	91
13	61	72	97
14	65	76	103
15	68	80	108
16	72	83	113
17	75	86	118
18	79	89	123
19	83	93	129
20	86	96	134
21	90	99	139
22	93	..	...
23	97	..	...
24	100	..	...
25	103	..	...
26	107	..	...
27	110	..	...
28	113	..	...
29	116	..	...
30	119	..	...
31	122	..	...
32	126	..	...
33	129	..	...
34	133	..	...
35	137	..	...
36	140	..	...
37	144	..	...
38	149	..	...
39	154	..	...
40	160	..	...

TABLE XI.—GROWTH OF PIN OAK (Q. PALUSTRIS), ILLINOIS.

Age Years	Diameter breasthigh (1) Inches	Height (2) Feet
10	1.8	9
20	4.2	20
30	7.4	33
40	10.6	46
50	13.2	58
60	15.2	69
70	17.1	79
80	19.0	87
90	20.7	94
100	22.4	100
110	24.1	104
120	25.7	108
130	27.4	110
140	29.1	113

(1) Based on decade measurements on 144 stumps, averaging 1.9 feet high.
(2) Based on sectional age counts on 20 trees.

TABLE XII.—GROWTH OF WHITE OR AMERICAN ELM (ULMUS AMERICANA), ILLINOIS.

Size at a given age		Time required to grow to a given size	
Age Years	Diameter breasthigh Inches	Diameter breasthigh Inches	Age Years
10	1.2	8	56
20	2.7	9	63
30	4.3	10	71
40	5.8	11	78
50	7.2	12	86
60	8.5	13	92
70	9.9	14	100
80	11.2	15	101
90	12.6	16	115
100	14.1	17	123
110	15.4	18	131
120	16.6	19	140
130	17.9	20	150
140	19.0	..	...
150	20.1	..	...

Based on decade measurements on 29 stumps, averaging 2.1 feet high, ranging from 25 to 228 years in age. Measured near Hardin, Calhoun County, Illinois.

TABLE XIII.—GROWTH OF OAKS AND BASSWOOD ON PRAIRIE UPLAND, ILLINOIS.

Age Years	DIAMETER INSIDE BARK AT STUMP, INCHES.		
	Black oak	Basswood	White oak
10	2.5	1.5	2.2
20	5.4	3.6	4.3
30	8.7	6.4	6.5
40	12.4	9.4	8.8
50	16.0?	12.0	11.0
60	....	14.6	13.0
70	....	17.0?	14.8

Based on decade measurements on the stumps of 62 white oaks, 14 black oaks, and 6 basswoods. Measured in northern and central Illinois by E. A. Ziegler.

main purpose of this investigation. Logging methods in Illinois make it very hard to get measurements of enough trees in one locality within a reasonable length of time. The figures given are intended to be used only in rough determinations, but they are of some value, as they are probably the only figures on the growth of pin and swamp Spanish oaks, and the only data on white elm in the Middle West.

TABLE XIV.—GROWTH OF OAKS AND BASSWOOD ON PRAIRIE UPLAND, ILLINOIS.

Size at Specified Ages.

Age Years	DIAMETER INSIDE BARK AT STUMP, INCHES.		
	Black oak	Basswood	White oak
10	2.5	1.5	2.2
20	5.4	3.6	4.3
30	8.7	6.4	6.5
40	12.4	9.4	8.8
50	16.0	12.0	11.0
60	....	14.6	13.0
70	....	17.0	14.8

DATA.—Stump counts taken in northern and central Illinois by Ziegler.
Stump height=1′–2′,
Black oak from 14 stumps, white oak from 62 stumps, and basswood from 6 stumps. Curves.

The figures for swamp Spanish oak *(Quercus pagodaefolia)* are divided into three classes: (1) dominant trees, or those which were especially vigorous and had overtopped the others; (2) intermediate trees, which might be considered as the average trees; and (3) suppressed trees, or those which were overtopped by the other two classes. Individual trees show a much faster rate of growth than is indicated even by the dominant figures, but the figures as given in all these tables are averages smoothed off by curves.

The Spanish and pin oaks and elm were all growing on fair bottom-soils, which are designated as quality 1. The pin oaks were largely young second-growth trees, while the Spanish oak and elm represent the growth of trees in older, more uneven-aged stands.

The figures given for the growth of black and white oaks and basswood on the edge of the prairie upland were obtained by a former party that worked in the state.

FOREST PROTECTION

FIRE

Fire is the most serious enemy with which the forester has to contend. Proper management of woodlands is impossible without protection from this danger. Fortunately, hardwood forests are subject only to surface fires, which are easier to prevent and to put out than any other kind. They are nevertheless very injurious, and their worst consequences are those which are least conspicuous. These comprise the damage to the soil, to reproduction, and to young growth.

An absolute essential to good soil is the presence of humus. It not only increases the amount of available plant food, but also affects the physical condition beneficially. Surface fires burn out this humus and destroy the leaf mulch from which it is formed. The results of this are worst on limestone and sandy soils, that are naturally hot and dry and become sterile, and on clays, which harden and bake. In every case the fertility and capacity to retain moisture are reduced. This damage to the soil will always show in a decrease in the vitality and rate of growth of the trees.

The damage to reproduction is very great; in fact so great that where fires are prevalent reproduction is entirely lacking. Not only are the many seeds lying on the ground destroyed, but the small seedlings, often unnoticed by the casual observer, are burned beyond recovery. If the seedlings are large enough and the fire light, the roots may survive and send up many small sprouts, which are often weak and are not a good basis for a thrifty stand.

Young growth of three or four inches in diameter or over, is seldom killed outright by light surface fires but is usually injured to some extent, especially at the base of the trees. Even large trees are gradually hollowed out at their bases by constantly recurring fires. Then, too, a dead log or a pile of brush around the base of a big tree will often cause such a hot fire that even the thickest bark will be burned through. These scars not only weaken the tree mechanically but also form an easy entrance to insects and rot-producing fungi. These infested trees then serve as places for the propagation of various tree-enemies which in time may spread to the healthy specimens. All forms of disease and insects are more prevalent in forests where the vitality of the trees has been lowered by frequent fires.

The benefits that are sometimes supposed to be derived from surface fires are of at least very doubtful value. The woods are often burned over with the idea of improving the grazing. By burning every year the brush may undoubtedly be kept small, but it will be increased in quantity, for where one small tree is killed five to ten sprouts take its place. With succeeding fires, the sprouts continue to decrease in quality and increase in numbers. Many weeds and bushes also come in readily on burned soil, and the quality of grass that thrives under these conditions is inferior. If it is thought necessary to convert a woodlot to pasture land with scattered trees, the result can better be accomplished by clearing with the ax and grazing a large number of cattle on a small area until the brush is killed.

Accidental fires are started by sparks from railroad locomotives and by hunters, campers, smokers, and others who are careless in the use of fire in the woods. They also sometimes spread from fires started by

farmers to burn brush or fallow land. These, as well as the intentional fires, may be greatly reduced by a strong public sentiment against forest fires, which would be aroused by a better understanding of their results.

The prevention of forest fires throughout the greater part of Illinois is a comparatively easy task, since most of the forest land consists of woodlots small in area and isolated by cleared land. Thus the individual owner can prevent this kind of damage by a reasonable amount of care in watching his lot in dry weather and by promptness in putting out any fires that start. This can be accomplished much more easily if the woodland is kept free from accumulations of inflammable material, such as dead trees, logs, and slash. Close utilization in lumbering will reduce the amount of wood ordinarily left in the woods, while lopping the tops of their side branches and scattering the debris will make it rot quickly. This material might otherwise feed a destructive fire.

Where woodlands lie in large and contiguous areas, as is the case especially in the rough lands of the Ozark hills and the bluff land along the larger rivers, the cooperation of owners of forest land and a good system of town firewardens will form the most effective measures of defense. A model fire law and a system of firewardens will be discussed under the heading: "A Forest Policy for the State."

It may be necessary over such large areas to perfect a system of fire lines along ridge tops and near railroads. Most of the woods in the rougher parts are now well provided with woods roads and trails along the ridges and valleys. Numerous instances were observed where even a narrow wagon track had been the means of stopping serious fires. If the existing roads were kept clear of inflammable material they would form the nucleus of a very effective fire-line system, and would be of great help in confining the damage to small areas and in acting as lines from which to fight the fires. The good telephone facilities of the farming districts will be a great help in notifying the owners of forest land of outbreaks of fire and in assembling them to fight those which are too large to be overcome by individual effort.

In many states, notably New York and New Jersey, the railroads are subject to very strict regulations in regard to fire, and are compelled to bear the brunt of fighting fires which occur along their rights of way. The railroads are often compelled to use spark arrestors and other devices to prevent the escape of sparks and lighted cinders from their locomotives, and to maintain patrols along their lines in dry seasons. In New York certain lines running through especially dangerous districts are required to use oil for fuel. In New Jersey they are required to maintain elaborate fire-lines wherever they run through

woodlands. A great deal can be done by even ordinary care in keeping clean the right of way and by making it the duty of trackmen and section hands to put out all fires they see.

While prevention of forest fires is of greatest importance, it is also well to know how to deal with them when once under headway. The following material on this subject is condensed from Bulletin 82 of the Forest Service.*

METHODS OF FIGHTING FIRES

The principles of fighting forest fires are essentially the same as those recognized in fighting fires in cities. The following are of first importance: (1) quick arrival at the fire; (2) an adequate force; (3) proper equipment; (4) a thorough organization of the fighting crew; and (5) skill in attacking and fighting fires.

(1) Quick access to fires is accomplished through the work of supervision and patrol in discovering fires before they have gained much headway, and by a well-developed system of communication through the forest by roads and trails.

(2) A small fire may be put out by one man, but in extensive forests several hours may pass before the fire can be reached. It is important to secure an adequate force of men and to get them to the fire quickly. In a well-organized system of patrol, the guard who discovers a fire communicates quickly to other guards and to headquarters by telephone, signal, or other means, and indicates the number of men he needs. It is essential that there be definite arrangements for securing a force of men in case of fire. This may be accomplished by cooperation with lumber or sawmill operators who employ forces of men, and through cooperation with local residents, or, in case of small tracts, through the cooperation of neighboring owners, each of whom agrees to assist his neighbor in case of fires. In some states there is a system of firewardens. In case of fire, the firewarden may call upon residents to assist in extinguishing it. They are required by law to repair to the fire in case of call, and there is a small statutory compensation for services.

(3) Just as in a city the efficiency of a fire service depends in large part on the equipment, so also in forest work it is essential that fire fighters be furnished with the proper tools and other equipment. The implements needed for fighting fires differ under different conditions. Wherever dirt can be used, the men should be provided with long-handled shovels. If water is available, buckets should be provided, and, where possible, bucket pumps. Under most conditions it is de-

*Protection of Forests from Fire, by Henry S. Graves, Forester.

sirable to have mattocks and iron rakes, and there should always be axes to aid in clearing brush or cutting through down-timber and old tops. In the protection of woodlots in settled regions, every farmer who repairs to a fire usually takes his own shovel, rake, ax, or other implement.

(4) It is important that there be in charge of the fighting crew some one in authority to thoroughly organize the work. A small crew well organized can do much more effective work than a loosely organized large crew. One of the advantages of the firewarden system adopted in a number of states is that the warden has authority not only to impress men to fight fire, but to direct their work.

The efficiency of the fire-fighting crew depends very largely on their skill and experience, and particularly on the skill and experience of the man directing the work. It is not only a question of knowledge of how to assign each man where his work will be most effective, but there must be judgment exercised in determining the general method of attack. The character of the fire, the character of the forest, the condition of the atmosphere, the strength and direction of the wind, the rapidity with which the fire is running, and many other points have to be taken into consideration.

(5) Small surface fires may often be beaten out. This is possible when the fire is burning chiefly in a dry leaf-litter or short grass. Where there are tops or piles of dry brush, or the fire is burning through thick brush or undergrowth, beating is very difficult.

There are various devices for beating. A blanket, coat, or riding slicker is often used. A gunny sack is one of the best implements for beating, particularly if it can be wet from time to time. A handful of green brush serves also very well for a beating device. In beating out a fire, one strikes the fire with a sideways sweep, driving the flames and burning material back upon the burned ground. A direct stroke scatters the fire.

The best way to extinguish running surface fires is to throw sand upon the flames. This method is, of course, practicable only when the soil is fairly clear of rocks and loose enough for ready digging.

Loose loam is also very good, but not so effective as sand. Heavy soil which clods is difficult to manipulate. Frequently sand or loose loam can be dug up in spots, but it is too stony to secure it all along the line of fire. The fighters must then supplement the use of sand or earth with beating or other methods. A very good method, where there is not much slash, is to make a narrow trace in front of the fire by raking to one side the leaves and other litter. As soon as the fire reaches the trace it is checked and readily beaten out. Sometimes, on level land and in open woods, a furrow is plowed as an emergency

fire-line. This same principle is used to check fires burning through young growth and brush where it is difficult to get at the flames. A narrow lane is cut through the brush ahead of the fire. This gives a space where the crew can work without hindrance. As soon as the fire approaches, it is attacked by all the crew with the various fighting devices with which they may be provided.

Sometimes the front of the fire is so fierce that it is impossible to meet it directly. One method, under such circumstances, is to direct the course of the fire. The attack is made on the sides near the front, separating the forward portion of the fire from the main wings. A part of the crew attacks the forward part and others run down and extinguish the wings. The front of the fire, attacked from the sides, is forced gradually and constantly into a narrower path. Usually the front can be directed toward some cleared space, road, pond, stream, swamp, or fire-line, when it will be checked enough to admit of a direct front attack. Sometimes by this plan the front may be rapidly narrowed by working from the sides, until it is at last entirely extinguished. The plan of giving direction to the course of the fire has often been successfully carried out when the fighting crew is too small for a direct attack.

When fires gain such headway that it is impossible to stop them by direct attack, no matter how numerous and efficient the crew or complete the equipment for fighting, back firing becomes the only means of stopping the fire. It should, however, be used only when it is absolutely necessary. One of the commonest mistakes in fighting fires is to overestimate the rapidity of the fire and the difficulty of putting it out.

If it is found that a back fire is necessary, a favorable point is selected directly in front of the fire, from which to set the new fire. This must be a point where it is safe to start a back fire, such as a road, fire-line, stream, or swamp. The leaves are ignited at points five feet to a rod apart for a distance not greater than the estimated width of the head of the fire. These small fires gradually meet and form a continuous line, eating back against the wind. A part of the crew is stationed across the road or other break from which the back fire is started, and put out at once the small fires which may result from the sparks blown over from the back fire.

The meeting of the two fires stops at once the head of the main fire. It is usually possible then to attack the wings with the ordinary methods of fighting. It is necessary to attack the wings at once, particularly if there is a strong wind, for otherwise each wing of the old fire would soon form an independent fire with a well-developed head. It is necessary, also, that a number of men be stationed where the orig-

inal fire and the back fire meet, in order to extinguish smoldering fires in tops, logs, and other debris. A fire is never out until the last spark is extinguished. Often a log or snag will smolder unnoticed after the flames have apparently been conquered, only to break out afresh with a rising wind. After the fire-fighting crew has left the ground it is always well to assign at least one man to patrol the edges of the burned area until it is certain that the fire is entirely out. This may not be for several days.

GRAZING

The custom of allowing cattle and hogs to run at large in the woods, while not as harmful in its effects as fire, is still detrimental. Since practically all the woodlands are fenced, it becomes a matter of individual judgment as to whether the woods shall be pastured or not. A great many owners wish to use their woodland for grazing, but they should realize that under such conditions they can not expect to get the fullest possible yield of wood from their forest lands. The most important phase of the grazing problem is that it encourages the thinning of stands that should be kept at a maximum density of crown-cover for the protection of steep slopes from erosion and the regulation of stream flow.

Hogs do damage principally by feeding on the seeds of various nut trees and by uprooting or barking young seedlings. Where a forest has sufficient young growth large enough to assure its safety, the presence of hogs in small numbers may be permitted.

Cattle do more damage than hogs, as they break down much young growth, trample the soil, feed on the leaves and tender twigs of the trees, and bark even fairly large trees at times. A forest in good condition will be too dense to allow the growth of grass and will thus be of no use for grazing purposes except to furnish a shady retreat for the cattle in hot weather. Wherever woods are extensively grazed they are invariably lacking in young growth and do not reproduce themselves, whereas a near-by woodlot protected from grazing will be fully stocked with thrifty young growth.

PREVENTION OF DISEASE AND INSECT INJURIES

Trees are commonly attacked by insect enemies and fungous diseases that do more or less serious damage. In some instances the value of the timber is destroyed or reduced through weakening or by the spoiling of its appearance. In other cases, the rate of growth is reduced by defoliation—a common injury to walnut and hickory throughout the state, and to catalpa in the southern part. Sometimes the trees are killed by the attack of defoliating insects.

The ordinary remedies of spraying with chemicals and the various devices of "tree surgery" as applied to shade and orchard trees are too expensive to use on a large scale in the forest. Nevertheless, the liability of a stand to disease or insect injury can be materially reduced by proper silvicultural methods.

If the principles of correct management are applied, the forest will be kept clear of unhealthy old trees that act as breeding places for insects and fungi, and will also be protected from overcrowding, fire, and other evils that weaken the vitality of trees and predispose them to disease. Well-spaced, thrifty, rapid-growing trees are seldom subject to injury from this source.

When a tree is found to be attacked by insects, the kind of insect infesting it should be ascertained, and the best time for cutting learned. If this is not done the tree might be cut when no insects were present, and very little or no check offered to their spread. This not only insures its utilization before its enemies have a chance to destroy it completely, but removes a dangerous source of infestation from which diseases or insects might spread to healthy specimens. The parts of trees not used should be immediately burned.

Cut timber should not be left in the woods, as it will not season well; and there is great danger of insect injury, especially to hickory, ash, oak, and elm. Peeling wood soon after it is cut will prevent the attacks of many destructive insects, and will at the same time hasten the seasoning process. This is especially true of hickory and ash, and of all cut logs in the southern part of the state where termites are abundant. The seasoned wood will resist decay much better than unseasoned, and the various forms of preservation, such as creosoting, will prevent both decay and insect attacks.

A Forest Policy for the State

The present condition of the forests of Illinois may be summarized briefly. There is a large area of land in forest—nearly a million acres in the twenty-six wooded counties estimated.* Most of this is more suitable for timber production than for agriculture. While the forests contain a great variety of valuable species, their silvicultural condition is very poor, owing to short-sighted methods of cutting and to injury from fire and grazing. Their productive capacity is therefore much below normal. The woodland is nearly all divided into small tracts and is owned chiefly by farmers, although some is in the possession of mining or other companies. The ownership is not especially subject to change, and therefore is favorable to forest management. On the

* See Table I, page 178.

other hand, there is, on the whole, little appreciation of the possibility and advantages of increasing the yield of forest land by proper methods of treatment. Practically all of the industries dependent on local timber supplies are on the decline. Those using bottomland timber must naturally be much restricted, since they get their raw material from a forest type which is not permanent. Those using upland timber suffer because of the depletion of the supply and the unnecessarily low production. The present output of forest products, amounting in 1909 to approximately one hundred and fifteen million board feet of sawtimber alone, can not be maintained unless better methods of forest management are instituted.

In view of these conditions, it is recommended that the state adopt a progressive forest policy to be administered through a nonpartisan Board of Forestry and a technically trained State Forester. The chief features of this policy should be: (1) the adoption of an adequate state fire-protection system, providing for forest firewardens in those counties where this seems desirable; (2) the inauguration of an educational campaign with the object of spreading the knowledge of scientific and practical forest management; and (3) further investigation of the problems involved in developing and extending Illinois woodlands. Such a policy is embodied in the following proposed forest law.

A PROPOSED FOREST LAW

AN ACT *to create a State Board of Forestry, to promote the Forest Interests of the State, and to appropriate money therefor.*

SECTION 1. *Be it enacted by the People of the State of Illinois, represented in the General Assembly:* That there shall be a State Board of Forestry consisting of the five following members: the President of the University of Illinois, the Dean of the College of Agriculture of the University of Illinois, the Director of the Illinois State Laboratory of Natural History, the President of the State Farmers' Institute, and one citizen of the State known to be interested in the advancement of forestry, who shall be appointed by the Governor, to serve for a period of five years. This board shall meet at least twice each year. The members shall receive no compensation, except the necessary expenses incurred in attending the meetings of the board.

SECTION 2. There shall be appointed by the State Board of Forestry a State Forester, who shall have a practical knowledge of forestry, and who shall be a technically trained forester. His salary shall be fixed by the board, and he shall receive besides, reasonable traveling and field expenses incurred in the performance of his official duties. He shall be provided with a suitable office at the University

of Illinois; and be entitled to receive from the Secretary of State such stationery, postage, and other office supplies and equipment as may be necessary. He shall act as Secretary of the State Board of Forestry. He shall, under the supervision of the State Board of Forestry, have charge of all forest interests in the jurisdiction of the State, direct the management of the State demonstration forests and collect data relative to forest conditions in the State. He shall have charge of all county firewardens in the State, and shall aid and direct them in their work, cooperate in forest work as provided in Section 4, and carry on a course of lectures on forestry at the Farmers' Institutes and similar meetings within the State. He shall give instruction in the College of Agriculture of the University of Illinois in forestry and silviculture, subject to the approval of the President and trustees of the University of Illinois. He shall prepare annually a report to the State Board of Forestry on the progress and condition of State forest work, and recommend therein plans for improving the State system of forest protection, management, and replacement.

Section 3. The State Board of Forestry shall have the power to purchase lands in the name of the State suitable for State demonstration forests, at a price which shall not exceed $20 per acre, using for such purposes any surplus money, not otherwise appropriated, which may be standing to the credit of the State Board of Forestry, and to make all rules and regulations for the administration of such lands as State demonstration forests; and the Governor is authorized, upon the recommendation of said State Board of Forestry, to accept gifts of land to the State, the same to be likewise held, protected, and administered under rules and regulations of the State Board of Forestry as State demonstration forests and to be used so as to demonstrate the practical utility of timber culture. Such gifts must be absolute, except for the reservation of all mineral and mining rights from and under said lands and a stipulation that they shall be administered as State demonstration forests, and the Attorney General of the State is directed to see that all deeds to the State of lands mentioned are properly executed, and that the title to such lands is free of encumbrances before the gift is accepted.

Section 4. The State Forester shall, acting under the supervision of the State Board of Forestry, when he deems it necessary to the best interest of the people and the State, cooperate in forest surveys, forest studies and forest protection, and in the preparation of plans for the protection, management, and replacement of trees, woodlots, and timber tracts, with any of the several departments of the Federal or State Government, and with counties, towns, corporations, and individuals, under an agreement that the parties obtaining

such assistance pay at least the salary or field expenses of the men employed in preparing said plans.

SECTION 5. Whenever the State Forester considers it necessary he may apply to the Board of Supervisors of any county to appoint, subject to his approval, a suitable resident of said county to be county firewarden to enforce the forest laws and to carry out all the purposes of this act. He shall serve for a period of two years and may be reappointed, but he shall be subject to removal at any time by the State Forester for cause. Such county firewardens and those assisting them shall, on the endorsement of the State Forester, receive compensation from the State for their services in carrying out the provisions of this section at the rate of not to exceed twenty-five cents per hour for the time actually employed, and reasonable expenses for equipment and transportation incurred in fighting or extinguishing any fire: *Provided,* that the total of such accounts shall not exceed $200 for each county in any one year; and the State Treasurer is hereby authorized to collect one-half of such wages and expenses from the county in which they are incurred. County firewardens thus appointed shall, before entering upon the duties of their office, take the proper official oath before the county clerk of the county in which they reside; after which they shall, while holding said office, possess and exercise all the authority and power held and exercised by constables at common law under the statutes of this State, so far as concerns the arresting and prosecuting of persons for violations of any or all of the provisions of this act.

SECTION 6. It shall be the duty of the county firewardens to enforce all forest laws of this State; to protect the State demonstration forests, and see that all rules and regulations in connection therewith are enforced; to report any violation of law to the State Forester at the time of its occurrence; to assist in apprehending and convicting offenders; and to make an annual report to him as to forest conditions in their immediate neighborhoods. When any county firewarden shall see or have reported to him a forest fire, it shall be his duty to repair immediately to the scene of the fire and employ such persons and means as in his judgment seem expedient and necessary to extinguish said fire. He shall keep an itemized account of all expenses thus incurred and send such account immediately to the State Forester: *Provided,* that no man shall be compensated for fighting fire on his own land or land that he holds under lease, or on land belonging to an employer, nor shall employees of railroad companies be compensated for fighting fires on their rights of way or on adjacent land, when said fires have started on the right of way or have been caused by sparks or ashes from any locomotive or engine.

SECTION 7. Any county firewarden who shall refuse to carry out the provisions of Section 6, or any able-bodied citizen who shall refuse to render assistance as provided by said section, shall be punished by a fine of not less than ten nor more than fifty dollars, or by imprisonment in the county jail for not less than ten days nor more than thirty days, or by both such fine and imprisonment.

SECTION 8. The Board of Supervisors of the various counties of this State are hereby authorized to levy and appropriate money for purposes of forest protection, improvement, and management, and said Board shall have recourse under an action at law for debt against any landowner, individual or corporation on whose account they shall have been obliged to pay out money for fighting fire for the amount which they shall have expended for such purpose.

SECTION 9. The State Forester shall furnish notices, printed in large letters upon cloth or strong paper, calling attention to the dangers of forest fires and to forest fire laws and their penalties. Such notices shall be distributed by the State Forester to county firewardens and posted by them in conspicuous places upon State demonstration forests, along the highways in forest-covered country, and in other public places.

SECTION 10. Any person who shall maliciously or wilfully destroy, deface, remove or disfigure any sign, poster, or warning notice posted under the provisions of this act, shall be guilty of a misdemeanor and punishable upon conviction by a fine of not less than fifteen dollars nor more than one hundred dollars, or by imprisonment in the county jail for a period of not less than ten days nor more than three months, or by both such fine and imprisonment.

SECTION 11. Every individual or corporation that carelessly, negligently or wilfully, maliciously or with intent, sets on fire, or causes or procures to be set on fire, any woods, brush, grass, grain or stubble, on lands not owned by such individual or corporation, shall be guilty of a misdemeanor, and upon conviction be punishable by a fine of not less than twenty-five dollars nor more than one thousand dollars, or imprisonment for not less than thirty days nor more than one year, or both such fine and imprisonment; except that camp fires sufficient to warm the person and to cook may be built on unenclosed and unposted land, provided proper precautions are taken to prevent the spread of such fire and provided it be totally extinguished before leaving such camp: *Provided,* that nothing herein contained shall apply to any person who in good faith shall set a back fire to prevent the extension of a fire already burning.

SECTION 12. It shall be unlawful for any person or corporation owning land to set or procure another to set fire to any woods, brush, logs, leaves, grass or clearing upon such land, unless all possible

care and precaution against the spread of such fire to other land shall have been taken by previously having cut and piled such brush, logs, leaves or grass, or having carefully cleared around the land which is to be burned, so as to prevent the spread of such fire. The setting of fire contrary to the provisions of this section, or allowing it to escape to the injury of adjoining land, shall be *prima facie* proof of wilfulness or neglect, and the landowner from whose land the fire originated shall be liable in a civil action for damages for the injury resulting from such fire and also for the cost of fighting and extinguishing the same.

SECTION 13. Whenever the State Forester or any firewarden of any county becomes convinced that a dangerously dry time exists, and that it is imprudent to set fire on any land, the firewarden shall post or cause to be posted, a notice in three public places in his county forbidding the setting of any such fire therein, and after the posting of such notices no person shall set any fire upon any land in said county, except for warming the person or cooking food, until written permission has been received from the firewarden of said county. All persons who start camp fires shall exercise all reasonable precaution to prevent damage therefrom, and shall extinguish the same before leaving them. Every person violating any provision of this section shall be punished by a fine of not more than fifty dollars, or by imprisonment in the county jail for not more than six months for each offense.

SECTION 14. Every railroad company shall keep its right of way clear and free from weeds, high grass and decayed timber which from their nature and condition are combustible material, liable to take and communicate fire from passing trains to abutting or adjacent property. No railroad company shall permit its employees to deposit fire, live coal, or ashes upon their tracks in wooded country outside of the yard limits unless they are immediately extinguished. Engineers, conductors, or trainmen who discover that fences or other material along the right of way or lands adjacent to the right of way are burning or in danger from fire shall report the same to the agent or person in charge at their next stopping place at which there shall be a telegraph station. Railroad companies shall give particular instruction to their section employees for the prevention and prompt extinguishment of fires, shall cause notices, which shall be furnished by the State firewarden, to be posted at their stations, and, when a fire occurs along the line of their road or on lands adjacent thereto, for which fire they are responsible, shall concentrate such help and adopt such measures as shall most effectually arrest its progress. Failure to comply with these requirements shall be a misdemeanor, punishable, upon conviction, by a fine of not less than ten dollars nor more than one hundred dollars for each and every offense thus committed.

SECTION 15. All individuals or corporations causing fires by violation of Sections 11, 12, 13, and 14 of this act shall be liable to the State and to the county in which the fire occurred, in an action for debt, to the full amount of all expenses incurred by the State or county in fighting and extinguishing such fires.

SECTION 16. Justices of the peace for this State, in the county wherein the offense shall have been committed, shall have jurisdiction to hear and determine all prosecutions for the purpose of enforcing fines and penalties, collectible under the provisions of this act, not exceeding the amount of one hundred dollars, and of holding the offender, under proper bail if necessary, for hearing before the circuit court, committing them to the county jail until such hearing, if required bail is not furnished. It shall be the duty of the State's attorneys of the several counties to prosecute all violators of Sections 11, 12, 13, and 14 of this act.

SECTION 17. All money received as penalties for violations of the provisions of this act shall be paid into the county treasury, and all moneys received from the sale of wood, timber, minerals or other products from the State forests, or recovered in civil suit as damages to the State forests as hereinbefore provided, shall be paid into the State treasury and shall constitute a State forest fund, which shall be disbursed only for the purchase of lands to be added to the State demonstration forests, and for the improvement and protection of said forests, by or upon the order of the State Forester, with the approval of the State Board of Forestry.

SECTION 18. There is hereby appropriated the sum of $10,000 per year for two years out of any funds in the State treasury not otherwise appropriated, for the payment of salaries and expenses other than those provided for in Section 5, and for the purchase of land as herein provided for.

SECTION 19. Expenses incurred under Section 5 shall be paid by the State out of the general fund, provided that not more than $2,000 be expended for this purpose in any one year.

SECTION 20. The Auditor of public accounts is hereby authorized and directed to draw his warrant on the State Treasurer for the sums herein appropriated upon the order of the chairman of the State Board of Forestry, countersigned by its secretary.

SECTION 21. All acts or parts of acts inconsistent with the provisions of this act are hereby repealed.

The present law in regard to forest fires is not sufficiently explicit, and provides no machinery for its enforcement. The proposed law contains the provisions that have been found most effective in other

states, as far as they are applicable to conditions in Illinois. The appointment of county firewardens has been made optional, so that the system can be started in a few counties needing fire protection the most, and then gradually extended to perhaps ten or fifteen of the more wooded counties as the benefit becomes apparent. The firewarden should be a strong and energetic man, should know the roads and trails of the county, and should be familiar with woodcraft. While the compensation must necessarily be very small, it should not be difficult to find public-spirited men willing to assume the responsibilities of the position. To insure the greatest efficiency, the county wardens are made responsible to the State Forester, who should advise and direct the fire-fighting force of the state. The expense of fire protection is divided between the state and county, since the general public, as well as the immediate locality, benefit through the maintenance of the forest cover. It is certainly the duty of the state to establish means for the protection of the timber crops of its citizens, not only to protect individuals from loss, but more on account of the close relation between the preservation of the forests and the general welfare of the community.

The educational side of the forest policy should be developed by the State Forester along every line that offers an opportunity to increase the general knowledge and practice of forestry. He should give instruction in the College of Agriculture of the University of Illinois and in connection with the Farmers' Institutes as well as publish simple and readable bulletins on forest management and planting. The course given in the College of Agriculture should not aim to give the students a full professional education in forestry, since it would not pay to absorb the time of the State Forester in invading a field already well filled by schools, many of which are better situated for the purpose. It should rather provide such instruction as will give the students a good general knowledge of the principles of forestry and enable them, especially those who expect to take up farming as a profession, to handle their woodlands to the best advantage. Another most valuable means of education would be practical demonstration of methods applicable to different sections and forest types in cooperation with private owners, or on tracts given to, or acquired by the state. Connecticut, Maryland, and New Jersey are examples of agricultural states having small forest reserves, which have been found very instructive for demonstration purposes.

In addition to this educational work, the State Forester will find many technical problems which will require scientific investigation. Many questions will arise in connection with methods of thinning and reproducing by natural means the second-growth woodlands of various types, that must be answered through study and experiment. The

subject of forest planting demands attention, in order that the best methods and most suitable species for various soils and uses may be determined. Important subjects in this field are the planting of waste land, such as sand dunes, and the growing of trees for fence posts and windbreaks. The State Forester can also cooperate with the federal authorities in studying problems which are nation-wide in their significance.

It would, of course, be possible to modify the proposed law by dispensing with the Board of Forestry and allotting its functions to a newly created department of the state University. While this is regarded as perfectly feasible, the organization provided for in the law is recommended as preferable on account of the importance which the administrative side of the work will undoubtedly assume, especially if the purchase of land for demonstration forests is undertaken. Most of the states which have made any considerable progress in promoting forestry have adopted this plan. In Wisconsin the organization of a Board of Forestry with a membership of similar character to that proposed for Illinois, has proved especially successful. Of course, the movement should be closely allied with the University, and this affiliation is provided for by the terms of the law and by the personnel of the proposed board. But whatever organization is adopted, it is of utmost importance that action be taken promptly. In view of the fact that Illinois has a small proportion of land adapted to timber production rather than agriculture, it is vitally necessary that such land be brought to and maintained at as high a state of productivity as possible. Moreover, the aggregate area involved, at least a million acres, is large enough to be worthy of attention in order that the citizens may learn how to make the best use of this land. Just as the state has found the need of agricultural experts to promote the welfare of her ordinary farm crops, so now it is in need of a forest expert to care for the timber crops. Illinois has long been a leader in the field of agriculture, and can not afford to delay in taking a place among the states which are encouraging the rational treatment of woodlands.

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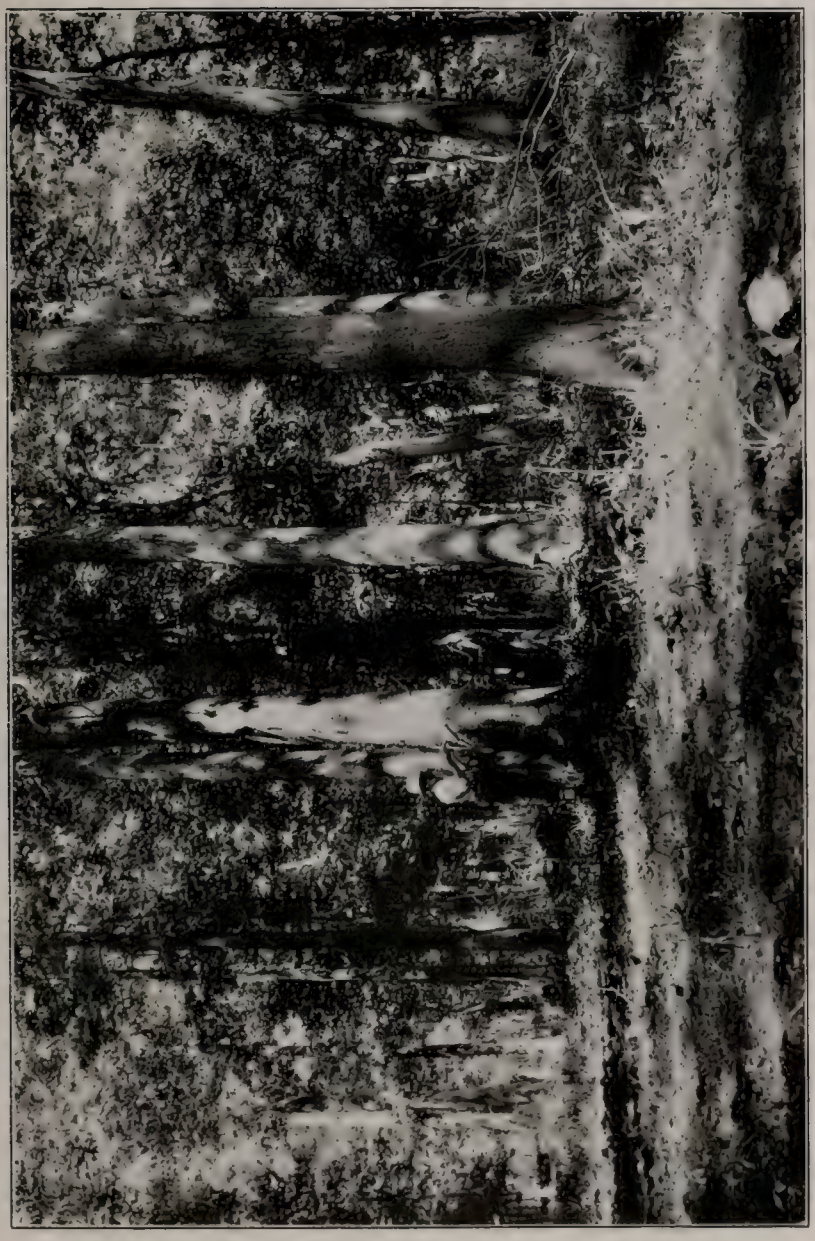
PLATE XXI.

Mature bottomland forest. Red gum, elm, and oak. Cache River, Pulaski County.

PLATE XXII.

Typical bottomland forest. Soft maple and pin oak. Big Muddy River, west of Benton.

Plate XXIII.

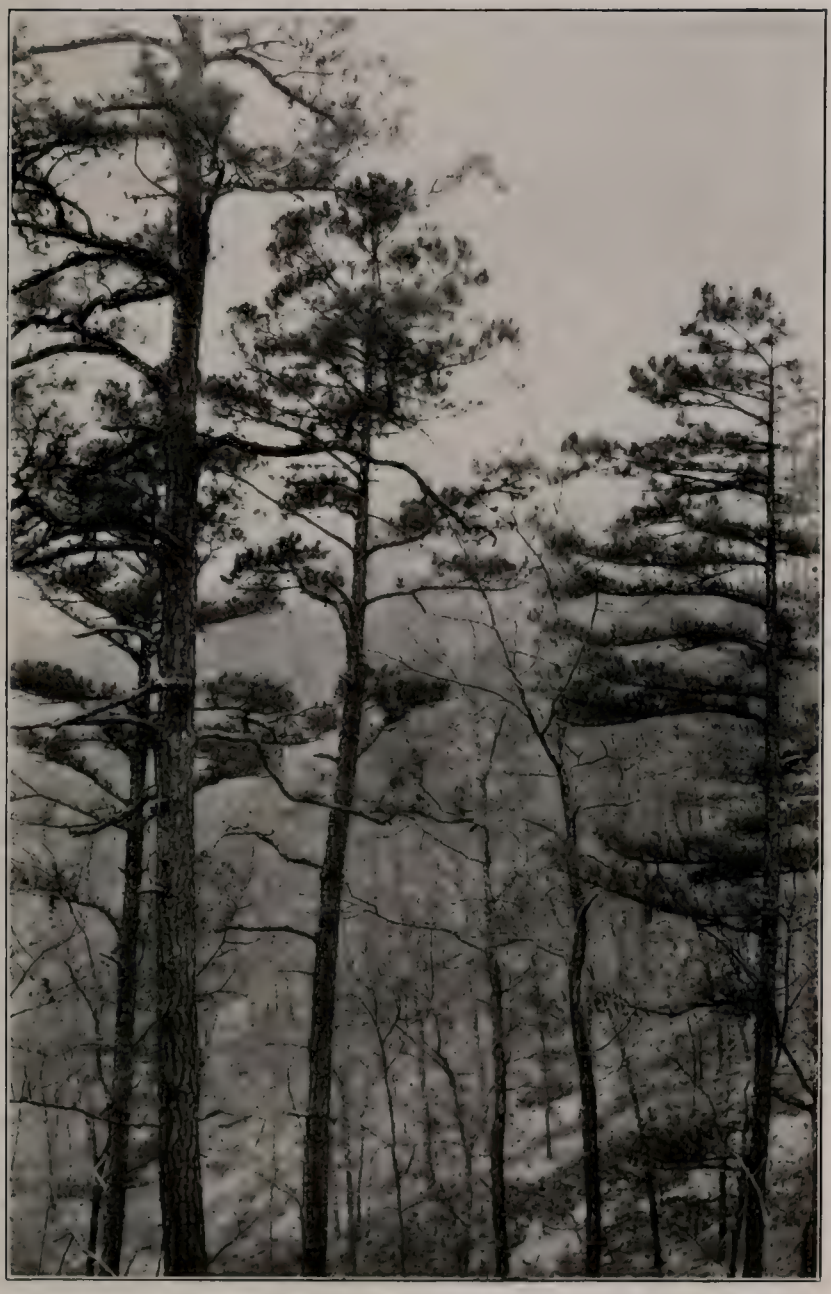


Swamp Spanish oak and red gum. A typical virgin stand on the bottoms of the Wabash River.

Plate XXIV.

A stand of virgin white oak. Upland hill type, Union County, near Alto Pass.

PLATE XXV



Shortleafed pine. "Pine hills" of Union County.

Fig. 1. Red gum flat near head of small valley, Union County.

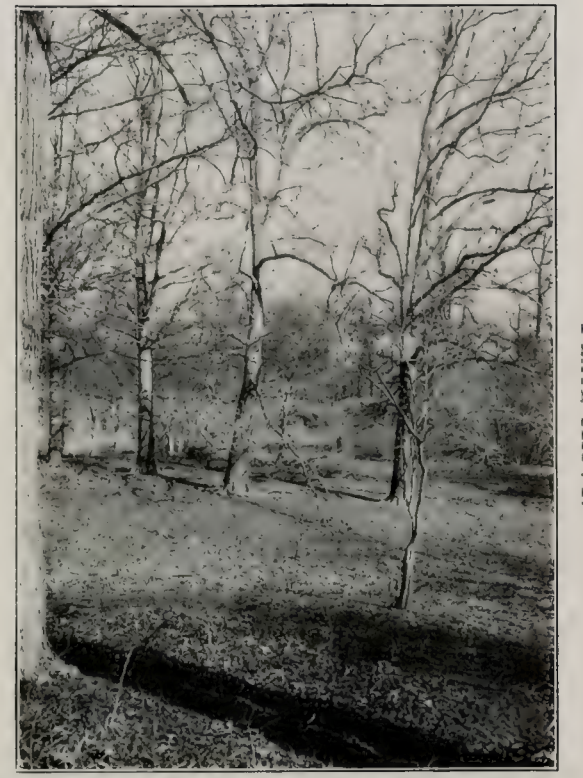


Fig. 2. Old white oak in scattered groups. Uplands of Union County.

PLATE XXVII.

Pastured bur oak grove. Boxelder in leaf. Jo Daviess County.

Plate XXVIII.

Young aspen (on right) encroaching on pasture land. Mixed stand of birch and bur oak in background. Jo Daviess County.

Plate XXIX.

Extreme erosion of soil (loess deposit) in Ozark Hill region.

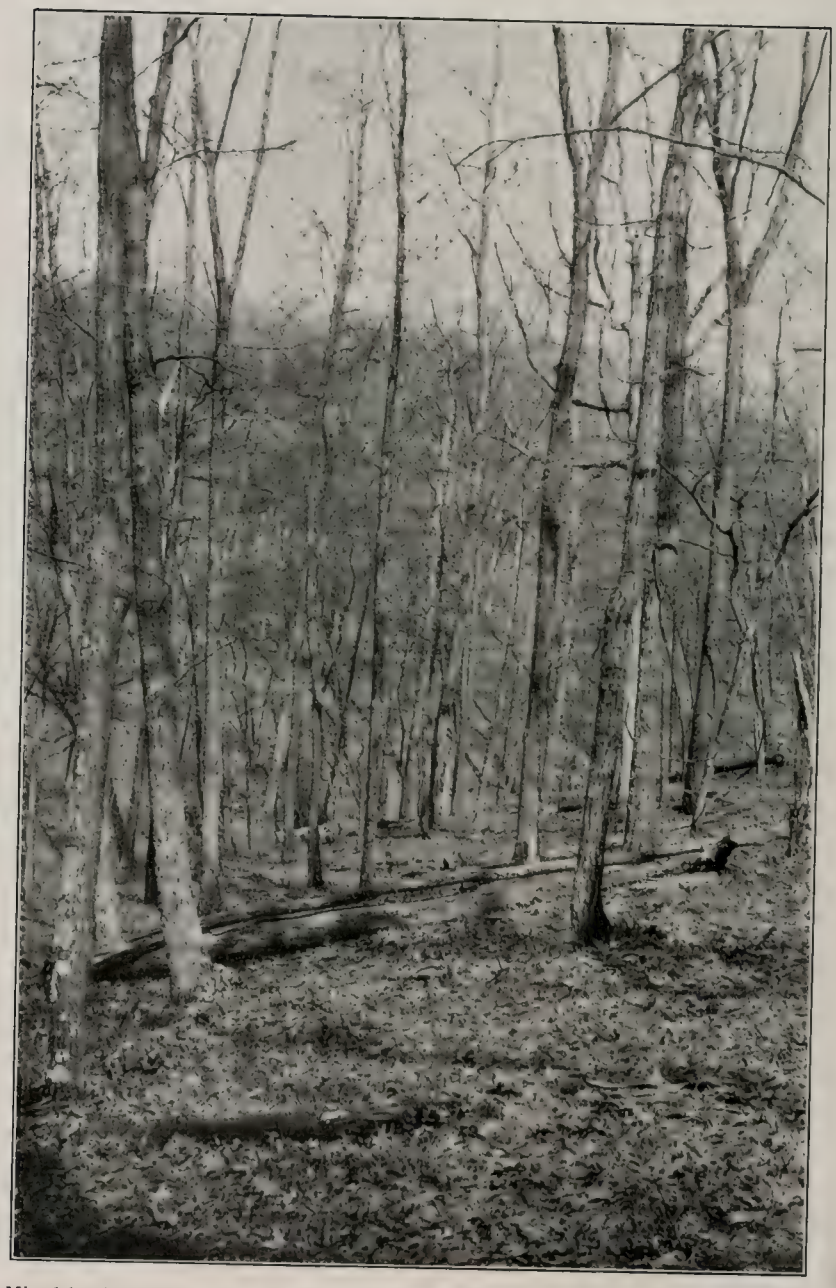
PLATE XXX.

Good mixed hardwoods slope in Jo Daviess County.

PLATE XXXI.

Overmature swamp Spanish oak on Big Muddy River bottoms, west of Benton. Note fire-damage at the butt. Trees of this class should be cut.

Plate XXXII.



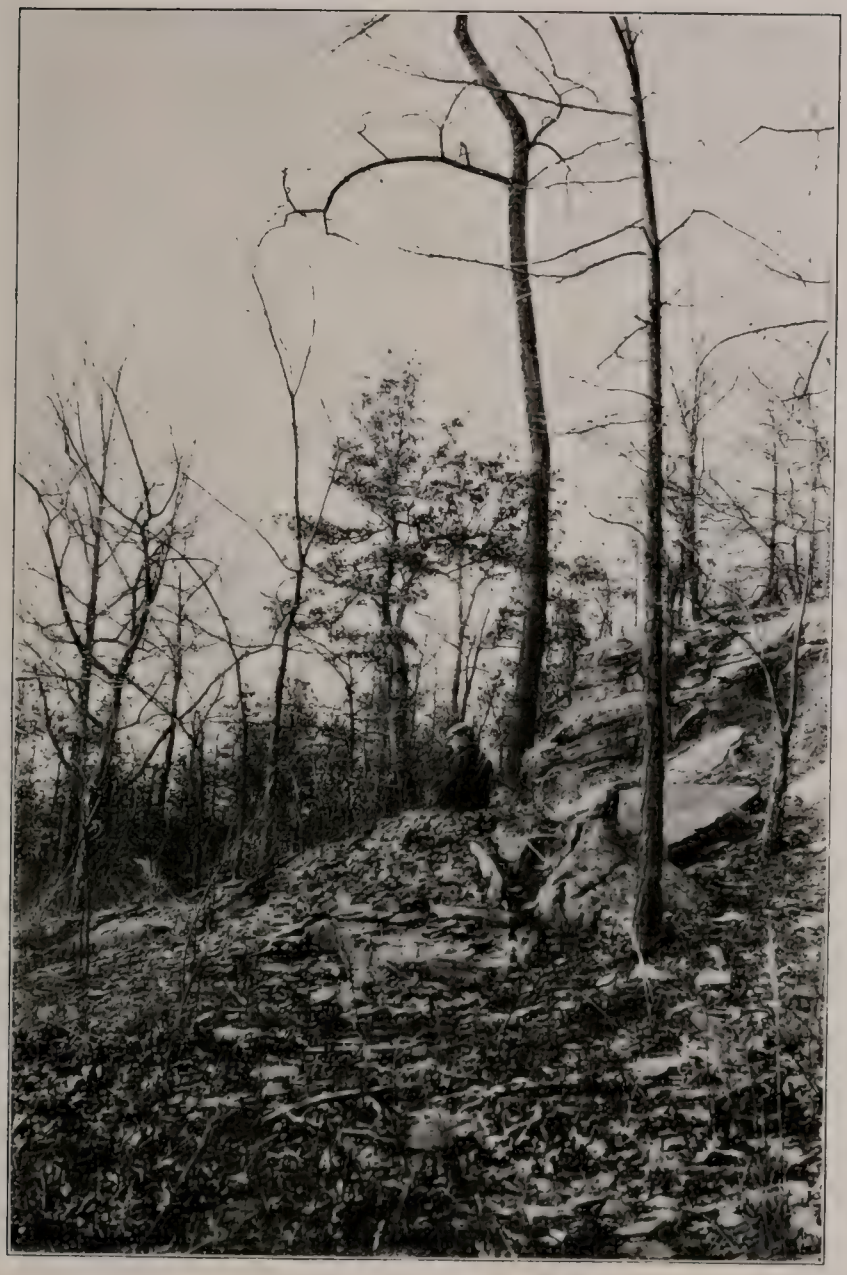
Mixed hardwood slope in Jo Daviess County. Rather too open in places and trees not all of good form. A careful cutting and protection from fire would improve the condition of the stand. Much good firewood is going to waste.

Open bottomland forest on Big Muddy River. Damage from ground fires is serious, the young oak and hickory on the left having been recently killed, and the larger trees fire-scarred at the butt.

Plate XXXIV.

A patch of aspen among mixed hardwoods, a type of low value resulting from fire. The aspen will be naturally eliminated if the forest is properly managed.

PLATE XXXV.



Upland hill type, Union County, second growth on upper slope, ash, mulberry, and oak, of poor quality due to repeated fires from a near-by railroad. A site that needs a protective cover of forest.

Plate XXXVI.

Swamp Spanish oak (*Quercus pagodaefolia*) showing typical bark. Saline County.

THEODORE FRISON
1915

BULLETIN

OF THE

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OF

NATURAL HISTORY

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ARTICLE V.—*The Vegetation of the Beach Area in Northeastern Illinois and Southeastern Wisconsin.* BY FRANK CALEB GATES.*

INTRODUCTION

During the university year of 1909-1910 at the University of Illinois, the results of the two previous summers' work on the area between Waukegan, Illinois, and Kenosha, Wiconsin, were presented in a bachelor's thesis, entitled "The Plant Associations of the Recent and Fossil Beaches of Lake Michigan between Kenosha, Wisconsin, and Waukegan, Illinois." The first half of the present article is taken bodily from that thesis, with whatsoever additions and omissions seemed most advisable.

The original article was written under the immediate supervision of Dr. H. A. Gleason, now of the University of Michigan. To him I am under the greatest obligations for innumerable suggestions both in interpreting the data and in putting them in written form. To Dr. H. S. Pepoon, of the Lake View High School, Chicago, to Dr. C. C. Adams, of the University of Illinois, and to Prof. L. M. Umbach, of Northwestern College, Naperville, Illinois, I am indebted for suggestions and other helpful features. The data for plotting the climatic factors were obtained through the courtesy of the Chicago and Milwaukee offices of the United States Weather Bureau; and the data for the levels of Lake Michigan, from the City Engineer's office, in Chicago.

The nomenclature used, is that of the seventh edition of Gray's Manual, since that is the latest taxonomic work.

The region under consideration is located near the northern limit of the type of vegetation known as the Deciduous Forest Province† and not very far from the eastern limit of an arm of the Prairie Province.‡ At the same time it is near the southern limit of the Northeastern Conifer Province§ and has within its area associations that are relics of that province.

*Submitted with spelling in accordance with the rules and recommendations of the Simplified Spelling Board.

†Deciduous Dicotylous Forest. WARMING, 1909:329 et seq. Deciduous Forest Province. GLEASON, 1910:43.

‡Prairie Province. POUND and CLEMENTS, 1898. Grass-steppe (Prairie). WARMING, 1909:285-86. Prairie Province. GLEASON, 1910:43.

§Evergreen Coniferous Forest. WARMING, 1909:315. Northeastern Conifer Province. GLEASON, 1910:43.

The aim of the work was to obtain a clear idea of the extent and floristic composition of the associations of the region to serve as a foundation for further work upon the successional relationships between the competing associations of the three provinces which are represented in the area.

Although the region had been visited for collecting purposes during some of the four years previous to 1908, work upon a strictly ecological basis was pursued only during the seasons of 1908, 1909, and 1910. A summary of the trips taken is here presented in tabular form.

Date.	Plants Collected.	Persons Accompanying Author.
June 8, 1908	Nos. 2448-2526	
June 29, 1908	2743-2779	Mr. N. L. Partridge and Mr. J. Sanford.
July 1, 1908	2780-2827	Dr. H. M. Pepoon, Prof. L. M. Umbach, and Mr. N. L. Partridge.
July 10, 1908	2828-2864	Mr. Carl Durand.
July 27, 1908	2865-2875	Dr. H. A. Gleason.
Aug. 3, 1908	2876-2907	
Aug. 7, 1908	2908-2924	Mr. Carl Durand.
Aug. 14, 1908	2925-2946	
Aug. 21, 1908	2947-2975	
Aug. 28, 1908	2976-2993	
Oct. 31, 1908	2995-2997	
Dec. 25, 1908		Mr. N. L. Partridge.
Jan. 1, 1909		Mr. R. R. Sleeper.
June 16, 1909	3014-3040	
June 22, 1909	3041-3065	
July 12, 1909	3078-3126	
July 19, 1909	3127-3163	
July 28, 1909	3164-3182	
Aug. 17, 1909	3201-3207	Mr. N. L. Partridge.
Aug. 24, 1909	3208-3221	
Aug. 30, 1909	3223-3259	
Sept. 4, 1909	3260-3278	
Sept. 11, 1909	3279-3284	
Oct. 17, 1909	3285-3292	
Nov. 24, 1909		
Dec. 25, 1909		
Mar. 24, 1910		
Aug. 13, 1910		Mr. A. G. Vestal.
Sept. 9, 1910		

Three nearly complete sets of the plants of the region were collected. One of these has been deposited in the Herbarium of the University of Illinois, another is in the author's private collection, while the third is in the Field Museum of Natural History, at Chicago, Illinois.

Location and Physiography

Geographically, this area is located along Lake Michigan, extending from Waukegan, Lake County, Illinois, to Kenosha, Kenosha

County, Wisconsin, lying between 42° 21′ and 42° 35′ north latitude and between 87° 48′ and 87° 49′ west longitude. The western boundary of the region under consideration, is the Glenwood ridge, which was the upper limit of glacial Lake Chicago, a brief discussion of which will presently follow. The region is entirely covered by the Racine (Wisconsin) and the Waukegan (Illinois-Wisconsin) quadrangles of the United States Geological Survey. The latter is by far the more detailed sheet and covers the greater part of the area. Parts of these two sheets have been used directly in making up Plates XXXVII and XXXVIII. Differences in elevation are very slight. The highest elevation on the Beach region proper is but nine meters, while virtually all of the area, with the exception of a few of the ridges, is less than five meters above the level of Lake Michigan. The Glenwood ridge, which forms the western boundary, is about seventeen meters above the Lake Michigan level.

Geologically the region consists of a sand and gravel beach superimposed upon glacial clay. In but one place, so far as was discovered, is the clay exposed. The sand is arranged in long ridges not quite parallel to the present shore-line. Between the ridges are swales, only a few of which are able to drain directly into Lake Michigan. Drainage is largely accomplished by seepage of the water through the sand and finally into the lake. In the vicinity of Waukegan, as indicated on the map (Pl. XXXVII), are two bodies of water located at practically lake level. These drain into the lake only during periods of rather heavy rainfall and during the spring thaws.

Physiographical History

The western boundary (Glenwood ridge) of the region under consideration was formed by Lake Chicago, the body of water that occupied the southern end of the Lake Michigan basin during the retreat of the Late Wisconsin Glacier. This glacial lake had a southwestern outlet into the Illinois River. By erosion of the outlet the lake level was reduced to 16.8 meters (55 ft.) above the present Lake Michigan. The process known as "stopping" caused a rather sudden transition from the Glenwood level to the Calumet level, which was about 10.6 meters (35 ft.) above the present one. During this period the ice-sheet retreated into the north until a low pass to the northeast was uncovered, which caused a lowering of the lake below the present level. A re-advance of the ice-sheet raised the water to approximately the 7.6 meter level which is known as the Tolleston stage. At this time Lake Maumee, which occupied the upper Erie and lower Huron basins, emptied into Lake Chicago through the Grand River,

which flowed across the present state of Michigan. Withdrawal of the ice-sheet uncovered an opening in the Mohawk Valley through which was drained Lake Warren, formed by the coalescing of the lakes in the Huron, Erie, Ontario, and Saginaw basins. Contemporaneous with this new outlet was the abandonment of the Grand River outlet into Lake Chicago. As the ice withdrew further, the lakes in the Michigan and Huron basins coalesced through the Straits of Mackinac, and the dismemberment of Lake Warren followed. With the uncovering of the Superior basin the lakes of that region together with those of the Michigan and Huron basins formed Lake Algonquin, which at first had a discharge through Port Huron and, at times of high water, through the Chicago outlet also. It seems possible that there may have been, in addition, an outlet to Lake Iroquois through the Trent Valley in Ontario. The land in the northeast began to rise when relieved of the weight of the glacier, and both Chicago and Port Huron outlets were in use until the Port Huron outlet was lowered, when this received all the drainage.

The next step was the opening of a pass near North Bay, Ontario, which resulted in what are termed the Nipissing Great Lakes. These were at a low stage and discharged through the northeastern outlet. Warping of the land there, however, finally brought the water up to the Port Huron level, and when the land in the northeast continued to rise the Port Huron outlet was resumed. From that time to the present, such changes in level as have occurred, are due to the widening and deepening of the Port Huron channel and to the fluctuations incident to variations in rainfall. Detailed accounts of the history of the lakes since the glacial epoch can be found in nearly any work dealing with the geology or physiography of the Upper Lakes region. The three following have been consulted especially:

Goldthwait, J. W. The Abandoned Shore-Lines of Eastern Wisconsin. Wisconsin Geological and Natural History Survey, Bulletin 17:2-9. 1907.

Goldthwait, J. W. The Records of the Extinct Lakes. Illinois State Geological Survey, Bulletin 7:54-68. 1908.

Leverett, Frank. Outline of the History of the Great Lakes. Twelfth Report of the Michigan Academy of Science, pp. 19-42. 1910.

The Beach area itself consists merely of sand-bars which were formed during the Tolleston stage, at which time the water was cutting into the Calumet ridge. The sudden drop in level which ended the Tolleston stage left these sand-bars emerged. Formerly this ter-

race extended along the whole border of the lake, but with the elevation of the water during the Nipissing stages the greater part of the terrace was washed away except in the Chicago district and in the area north of Waukegan. This interpretation, which signifies that the ridges are of about equal age, is substantiated by observations upon the plant associations. Jennings, in his work on Presque Isle (1909: 294-305), under "historical development," says that the ridges were formed at different dates, and that a line of plant successions could be traced which confirmed the physiographic interpretation. In the Beach area, however, evidence goes to show that, with the exception of the fringing dune from Zion City down to Waukegan, the ridges were formed at one time. The fringing dune, as it now exists, is undoubtedly a product of historic times. Since the building of the piers to protect the harbor at Waukegan, considerable sand has accumulated north of it, and the formation of a new dunal ridge a little north of the pest-house is now (1910) beginning to show. North of Zion City, particularly between Winthrop Harbor and Kenosha, the shore-line is being washed away a noticeable distance every year. These ridges are all oblique to the present shore-line but they are parallel, or very nearly so, to the shore-line that existed at the time of their formation, namely, the Calumet ridge. The work of erosion, which bid fair to allow the lake access to the Glenwood ridge south, as well as north, of Kenosha, has been to a considerable degree, checked by piers at Kenosha and by breakwaters, behind which the lake is being artificially filled.

Climate

As there are no weather bureau stations in the region having records of long duration, the records of the stations at Milwaukee and Chicago, situated at equal distances north and south of the area, are used. It is fairly safe to assume that the records for this region in very similar sort of country may be obtained by interpolating those given. It is recognized that these data do not actually give the conditions under which the plants live, but only a general indication of the climate. The records are given in curves to facilitate interpretation (Pl. XL-XLII). As climatic factors do not usually have edaphic influence, they are of value only in determining the general character of the vegetation that will occupy a given area.

Edaphic Factors

Far more important than the climatic factors in determining the floristic composition within an area are the edaphic factors. Of

these, the most important in itself is probably water. This region is abundantly supplied with precipitation quite uniformly distributed throughout the year. In addition, it lies in the immediate proximity of the water-table level of Lake Michigan, which makes it to a large degree independent of precipitation. The sandy soil is quite favorable for furnishing the plants with water, which the particles of sand hold as capillary films. The physiological supply is probably about 95 per cent. of the physical supply.

What seems the second factor in importance is the food material in the soil. Sandy soil is notably deficient in soluble food material. The relatively rapid eremacausis* characteristic of sandy soils, caused by ready admission of atmospheric oxygen, accounts for the destruction of much of what would have been available plant food under other environmental conditions. Furthermore, soluble materials, and even insoluble ones, are gradually leached out of the soil as the rain percolates through it instead of running off as it does in most soils.

With respect to light, plants of the sandy soils thrive best with a maximum, and this partially explains the lack of density in the vegetation under trees on the sand. Wind has a marked influence upon the vegetation of the dune regions, although for the most part its action is upon the environment directly and upon the plants only more or less indirectly. Wind increases the evaporation of water from the plants, but many of those which are modified to reduce transpiration have an abundant supply of water, so, at least to a certain extent, such modification is inherent in the species and is not provoked by the direct effect of the environment.

Influence of Lake Michigan

Lake Michigan exercises a leveling influence upon the region in so far as temperature is concerned. The most evident influence is, of course, upon the shore itself, which in places is built out and in others is torn down. This has had a very marked effect upon the beach associations, which will be discussed in the proper place. The fluctuations of the lake within the last sixty years are shown in Plate XLIII. Tidal waves are of rare occurrence (May 12, 1905, and April 29, 1909). They may violently modify the vegetation, but they do not occur sufficiently often nor are they sufficiently powerful to permanently modify it. Such waves are seldom over 1.5 meters

*The state of affairs in which humus-forming matter is so rapidly oxidized that no humus is formed.

high, and they are so short in their duration that the fringing dune has practically always been able to protect the land behind it. Once the average lake level is such that the water is at the foot of the ridges and prairies, as at Kenosha, no vegetation can prevent the steady cutting which gradually eats away the ridges, prairies, and marshes. Piers are built to combat this erosive action, but as a rule they merely retard it and do not stop it.

General Description of the Region

The region lying between the Glenwood ridge on the west, Lake Michigan on the east, Kenosha on the north, and Waukegan on the south is very shallowly crescent-shaped. Its northern and southern boundaries are marked by the extensions of the Glenwood ridge into the lake as cusps. The length of the area is about 25 kilometers with a width of from 0.4 to 1.6 kilometers. The elevation above Lake Michigan level varies from 0.8 to 9.0 meters. The soil is sandy throughout.

As seen from the Chicago and North Western railway, which skirts the western edge, the different parts of the region give the following general impressions: From Waukegan to a kilometer north of the Lake County pest-house the land is characterized by marshy swales separated from one another by very low sandy ridges. In no place are these ridges two meters above the level of Lake Michigan. The vegetation is essentially prairie-like. It is very monotonous in appearance, except during July, when the lilies are in bloom, and during September, when it is covered with blazing stars. The swales are uniformly occupied with swamp grasses and sedges, all of which appear very much alike from the train. There are, at very long intervals, scraggy trees which hardly break the monotony.

North of this area is another which, though of the same physiographic character, gives an entirely different impression because of the groves of pines that occupy the ridges. In consequence this portion is termed the area of the pines. It is bounded on the west and north by arms of the Dead Lake. Formerly the extent of this area was much greater both north, south, and west; but upon those sides it is being reduced by cutting, burning, and by natural successions, while the fringing dune and the lake form its eastern boundary.

From the Dead Lake north to Kenosha is the area of greatest extent. It is wooded, but in this case the trees are oak instead of pine. There are many blowouts, those towards the north being larger and slightly more numerous than those in the southern part. The interridgial depressions, which are not so low as those towards

the south, are, for the most part, wider, and are occupied by prairie rather than by marsh plants. At the Illinois-Wisconsin state line the innermost oak ridge has been cut away, leaving an area of level sandy ground, one kilometer in width, from the lake to the bluff, in which the highest elevation above Lake Michigan is scarcely 0.5 meter.

Nearer Kenosha occurs the last oak ridge (Pl. XLIV, Fig. 1), which is quite wide and has several large blowouts in its sandy soil. The end of this ridge is about a kilometer south of Kenosha. It is being rather rapidly cut into by Lake Michigan. A little north of the end of this ridge, and protected by it on the south and west, occurs the only traveling dune of this area. It is very small in comparison with those at the head of Lake Michigan. The part between the oak ridge and the railway track is a sodded, sandy plain.

Just south of Kenosha measures have been taken to prevent the rapid cutting away of the shore that had been going on. Consequently the natural conditions have been destroyed. A little north of Kenosha the Glenwood ridge has been cut into by the lake, and there the region under consideration terminates.

Associations: General Consideration

In the naming of the ecological units there is still a confusion of terms. In this article the name "association" is used to designate these units; and by an association is meant a group of living forms whose epharmony (ability to live with other forms in a given environment) enables them to live together as a uniform or homogeneous area of definite biotic composition.

Although animals are not given consideration in this article, it must not be forgotten that they are an essential part of the association, especially the smaller animals. Their ecological relationships and correlations have, in general, not been sufficiently worked out to accord them their proper consideration.

The term *association* rather than *formation* has been used for the name of the ecological unit because of its priority* and its natural fitness. The term *formation,* as originally proposed by Grisebach,† was clearly intended to connote a broader group than the simple ecological units which he mentions but to which he does not apply a name directly. To use the term formation as the name of the

*Humboldt, 1807. Essai sur la Géographie des Plantes, p. 17.

†Grisebach, 1838. Über den Einfluss des Klimas auf die Begrenzung der Natürlichen Floren. Linnaea, 12:159-200.

ecological unit, as several modern writers have done, is clearly a misinterpretation of Grisebach's statement. Warming (1909) definitely uses the word *association*, which he explicitly states is not synonymous with Grisebach's "formation" but is included under it.*

Approaching the question from an analytical standpoint, Warming (1909: 140-145) defines a *formation* as "an expression of certain defined conditions of life" which "is not concerned with floristic differences," and an *association* as "a community of *definite floristic composition* within a formation"; to which he adds: "it is, so to speak, *a floristic species of a formation which is an ecological genus*". The ecological unit (association) is equivalent to the taxonomic unit (species). Just as species are grouped to form a genus and genera are grouped to form a family, so are associations grouped to form a formation and formations grouped to form a province. If necessary, an association may be divided into consocies, in like manner as species are divided into subspecies.

Of the apparent properties that ecological associations and taxonomic species have in common, Harper (1906: 33-34) gives the following very pithy statement: "There are many analogies between habitat-groups and taxonomic groups, such as species, though the latter are mutually exclusive categories and the former often are not. For instance, both are able to be discovered, described, named, and associated with certain type-localities. Records of both may be preserved by descriptions, photographs, measurements, and other means. Both have their diagnostic characters, with more or less variation and intergradation. Both have passed through processes of evolution, are self-perpetuating, and are liable to disappear through geological or climatic changes or the works of man. New ones may also originate, suddenly or gradually. Both have more or less definite geographical distributions and regions of best development. Both are capable of being subdivided, combined, or relegated to synonymy, with the increase of our knowledge concerning them. Habitat-groups, like species, can also be aggregated into larger categories analogous to genera and families".

Just as genera and species present difficulties of delimitation, so do formations and associations. The difficulties of ecological classification show many points of similarity, and require fully as much

*For a detailed discussion of the questions involved the reader is referred to the following articles:

Smith, Robert. On the Study of Plant Associations. Nat. Sci., Vol. 14. 1899.

Warming, E. Oecology of Plants, p. 139-148. 1909.

Moss, C. E. The Fundamental Units of Vegetation. New Phytologist 9:18-53, 1910.

study and experience for solution as do those of taxonomic classification. The criteria that have been used in delimiting and classifying associations have been almost as various as writers upon the subject.

Jaccard (1902:350) says, "Im allgemeinen ist der Bestand bestimmt durch die dominirende Art oder Arten". He was the first to set up a mathematical criterion for distinguishing associations. The association- or community-coefficient (Gemeinschaftscoefficient) is obtained by dividing the number of common species, in the two areas under consideration, by the total number of species in them. For example, area A has 100 species, area B has 120 species, 60 of which are common to the two areas. Then $\frac{60}{100 + 120 - 60} = 37{\cdot}5$ per cent. the community coefficient. For areas which are in the same association and in the same locality this coefficient ought to be fairly high. That even this method has its limitations Jaccard recognized when he said, "Sie entsprechen zwar gewissen Differenzen in den ökologischen Bedingungen der verglichenen Territorien, aber es besteht zwischen dem absoluten Werth dieser Differenzen und dem der Gemeinschaftscoefficienten keine mathematische Proportionalität." The same method was independently arrived at by Professor S. A. Forbes in a statistical study of Illinois Fishes.*

Besides the floristic composition told by mathematical methods, associations are usually appreciated by any or all of the following characteristics: (1) the presence of one or more dominating species, (2) the presence of tension lines at their boundaries, (3) the presence of evidence of dynamic succession, usually shown at or near the tension line, (4) the presence of a uniform environment, (5) the inability of species of different associations to mix, and (6) the presence of similar vegetative forms and environmental adaptations.

The association itself is composed of one or more principal or dominating species, termed the *dominant species,* which give the fundamental character to the association. In some associations the dominant species may be the only species, but more usually the interstices between the plants of the dominant species are occupied by what are termed *secondary species.* Frequently secondary species by their showiness give the color tone to the association. Where this varies from season to season, these different appearances are termed the seasonal *aspects. Succession* occurs when, in a given area, one association displaces another. Successions trend toward a definite cli-

*On the Local Distribution of Certain Illinois Fishes: An Essay in Statistical Ecology. Volume VII of this series, Article 8.

matic association which, if conditions were ideal and sufficient time were allowed, would occupy the whole of the given area. The series of associations which succeeded one another from bare ground to the climatic type is known as a *genetic series*. It is not necessary, however, that successions in a given area should proceed according to the normal genetic series. Mishaps of various kinds are continually occurring to prevent this. Successions are recognized primarily by the presence of pioneer or relic species within a given association. A *pioneer* species, as its name implies, is a species of a given association that can invade a genetically lower association, and a *relic* species is a species of a preceding association which remains after a successful invasion, thereby giving a clue to the situation. From this it follows that a complete association—if one may be allowed to use that term in this connection—consists of dominant species, secondary species, whose varying seasonal dominance produces seasonal aspects, invaders or pioneer species of a succeeding association, relics of a former association, together with such ubiquitous species, which seem to have little or no restriction placed upon their distribution, as may occur there.*

Successions form the most satisfactory approach to the ecological study of a region, and for this reason it may be well to give the subject brief consideration. As mentioned above, successions are often easily recognized in an association by the presence of pioneer or relic species. When associations within one formation are concerned, succession usually takes place by the invasion of the secondary species of the invading association, and the succession may be said to be completed when the dominant species have made their appearance. In the case of the invasion of an association of one formation into an area occupied by an association of another formation, invasion is effected by the dominant species, with the subsequent appearance of the secondary species. As one would naturally expect, invasion of one formation into another takes place through the pioneer association, which is characterized by a paucity of species, relatively speaking, and, consequently, in such an area the vegetation consists of the dominant species of the invading association with such of the species of the invaded one as can live under the new conditions. These secondary species are existing there as relics, yet they comprise virtually all of the secondary vegetation. This same principle holds also

*For further discussion of the association consult:

Clements, F. E. Research Methods in Ecology. 1905.

Cowles, H. C. The Causes of Vegetative Cycles. Bot. Gaz. 51 :161-183, Mar., 1911.

for the invasion of one province by another; that is to say, the dominant species of the invading association are the pioneer species in the invasion. Many other general principles concerning succession might be given, but as Adams has summed up "Some Principles of Succession" the reader is referred to "An Ecological Survey of Isle Royal, Lake Superior," pages 146 to 149, (1909) for their statement. A relic species exists in a given association because it occupies ground which as yet is not tenantable by any of the species of the succeeding association, rather than because the succeeding association can not displace the relic. An invader occupies more nearly its optimum habitat, but the relic lives where the other plants seem not to be able to develop. The disappearance of the relic usually takes place with the death of the individuals, whereupon the bit of ground which it occupied may be taken up almost immediately; or again —and many instances are at hand—the spot may remain bare for some time to come. Some relics modify the structure of their vegetative parts and continue for a long time after the invasion has been completed. Junipers and *Rhus canadensis illinoensis* (sumac) are two very good examples of this class of plants.

The naming of the associations has been approached from many different view points, but the most natural course seems to be to use the name of one or more predominating species, and, accordingly, that method is adopted in this article. In cases where another investigator has found associations clearly the same as those of the Beach area, the name that he used will be given first consideration, priority being regarded in so far as the fitness of the subject will permit.

The Lower and Middle Beach Associations

As the waters of Lake Michigan receded, a sand beach was exposed. This furnishes the starting point of a genetic series of associations which is known as the beach succession. Bare sand and the water of the streams and lakes are the two initial points of primary successions in this area.

THE CHLAMYDOMONAS ASSOCIATION

The classification of lake beaches has usually been founded upon a physiographic basis, in which the features distinguished are lower, middle, and upper beaches. The "lower beach" of Lake Michigan has been defined by Cowles (1899:113) as "that zone which is situated between the water level and the line reached by the waves of common summer storms." He gives an alternate definition on page 114: "It

might almost be defined as that portion of the beach which is devoid of vegetation." The lower beach of the Beach area physiographically speaking, exists in two modifications, one consisting of a very gradual slope, which may be concave, and the other of a relatively steep slope. Beaches of the first type are but very little elevated above the average level of Lake Michigan. The sand is damp, either to the very surface or, at least, to within one or two millimeters of it. Just at the edge of the lake is a little ridge which permits water to be retained beyond it. This water forms what is termed a beach pool. Being almost at the level of the lake, drainage back into the lake is very slow. In rainy seasons or at times of frequent north to southeast winds the beach pools may remain for a long time. During the ordinary growing season the sand is never sufficiently dry to be blown about in the wind. In beaches of the second type, the slope is much greater and the water from each wave drains away very rapidly. As a result, two to three centimeters of dry sand form the surface. This sand is, of course, easily blown about in the wind.

Neither of these two types of the lower beach bears vegetation of a permanent nature. In beaches of the first type, the one-celled, motil alga, *Chlamydomonas,* together with *Oscillatoria,* may occur in such numbers as to cause the wet sand to appear green. This constitutes the *Chlamydomonas* association. These algae occur also in the waters of the lake, but their optimum habitat seems to be the beach pools which occur near the outlets of sewers or near the mouths of creeks bearing sewage. (See Plate XLIV, Fig. 2.) The sand around the pool is mushy and rather greenish in color. The ridgelet between the beach pool and the lake is very low (10 cm. at most) and very narrow. Every north to southeast wind will cause the waves to run over the ridge and flood the pool with sewage-laden water from the nearby sewer. This constant flooding, together with the rather frequent rains, resulted in a permanent pool during the season of 1909. Small snails appeared, and upon them as well as upon other living forms the sanderlings shown in the figure are feeding.

Aside from the algae, vegetation upon the lower beach is purely accidental. One such case is that of a large willow log which was broken in three pieces and washed up to the edge of the lower beach by the tidal wave of April 29, 1909. The original source of this log is not known, for nowhere in the Beach area are there willows of such size. The logs lie just within the reach of every ordinary wave. Succeeding storms have partially covered the logs with sand, which is constantly kept moist by the waves. From the logs themselves,

shoots have grown up six decimeters. Whether these logs will withstand the winter storms and, together with some wreckage near by, originate another ridge remains to be seen.

Another case of accidental vegetation on the lower beach is very temporary in duration and extent. It occurs south of Kenosha, where Lake Michigan is cutting into the prairie. Some prairie plants, notably loosestrife (*Lythrum alatum*), are carried bodily from the prairie and are occasionally left stranded with their root systems in the damp sand of the lower beach. They remain living until washed away altogether by a succeeding storm.

The part of the lower beach which is devoid of plants comes next into consideration. The area is bare because plants can not obtain a footing there—and not because they will not grow there. The reasons which are given briefly by Cowles (1899:114) and more fully by Jennings (1909:310) are as follows: the alternate washing by storm waves and the severe drying out under the sun, combined with the washing about of the sand when submerged and its blowing about when dry, prevent the establishment of any plants whose seeds actually do germinate. After a rainy spell of two or three days' duration, such as August 13-15, 1909, it is not at all a difficult task to find, scattered over the slightly damp sand, seeds which have begun to germinate. With the reappearance of the sun and the drying of the surface sand, these partially germinated seeds dry up and are blown about by the wind. That living forms, however, can maintain themselves on this area is clearly shown by the industry of the turnstone (*Arenaria interpres*), which, during its brief sojourn in this region in the spring and fall migrations, is continually occupied in ferreting out the small insects and other animals which are found under the pebbles.

The junction of this area with the portion of the beach continually washed by the waves is the location of the willow log and wreckage previously mentioned. One piece of wreckage, a little over a meter in length, projects somewhat over a decimeter into the air. The ordinary waves just fall short of its lakeward side. On the landward side, stretching southwestward, is a miniature dune of sand in which are growing the following plants: *Juniperus horizontalis*—a single healthy shoot, 3 cm. in length, growing next to the wreckage; *Prunus pumila* (sand cherry)—a sprawling shrub; *Poa compressa* (English blue-grass)—a few plants; *Potentilla anserina*—one plant with five radiating runners; *Equisetum arvense*—a few plants; a composite which was so depauperate as to be unrecognizable; and a convolvulaceous plant, together with the exposed roots of *Calamovilfa longifolia*. A wagon track through the dune explains the planting of

the *Potentilla,* the composite, the *Equisetum,* and the convolvulaceous plant, for they were growing in the bottom of it. The nearest source for the *Juniperus* was about a hundred meters away, from which the seed may have been carried by the gulls which are abundant on the beach and occasionally are seen in the heath. Close to the lee (southwest) side of another piece of embedded wreckage in this same vicinity was a straggling plant of *Xanthium commune* (cocklebur).

Taking all these facts into consideration, it seems evident that a new ridge is being thrown up. The pieces of wreckage were probably lodged there during the violent storm and tidal wave of May 12, 1905. The juniper came in in the backwash of that storm or by some other agency, as suggested above, in 1906, as it appeared to be three or four years of age (1909). The storm and tidal wave of April 29, 1909, did not dislodge the wreckage nor the juniper. It added material that can assist in the formation of a ridge. Progress towards that end, however, is very slow.

The *Chlamydomonas* association is entirely identical with the *Chlamydomonas* formation of Jennings at Cedar Point (1908:313) and at Presque Isle (1909:310). Occasional presence of the alga was reported by Cowles near Porter, Indiana, (1899:114). This association, together with the plantless area, composes what MacMillan termed the "front strand."

The Cakile-Xanthium Association

From the upper limits of the open sand of the middle beach, and therefore out of reach of the ordinary storm-waves, an area of sparsely vegetated sand stretches inland. This is the location of the *Cakile-Xanthium* association. The landward boundary of this area is usually the fringing dune.

Physical Environment.—The physiographic characteristics of this association are fully discussed by Cowles (1899:115-117) and by Jennings (1909:311). The middle beach, as Cowles designated it, lies "between the upper limits of the summer and winter waves." It is dry in summer, and differs from the lower beach only in that it is not subject to the mechanical violence of the waves during the growing season. The soil is, for the most part, sand whose grains vary between 0.2 and 1.0 mm. in diameter. It is exposed to the full force of wind and sun, and consequently it is very dry nearly all of the time. During the daytime the sand may become very hot (60° C.), but it cools off rapidly during the evening. Although the upper few centimeters are so very dry, the sand beneath is always moist and may even be wet.

Ecological Characteristics.—The plants that persist in this association possess certain general characteristics: (1) they are annuals, because perennials are uprooted during the winter storms; (2) their disseminules are comparatively heavy, so that altho they are blown about they are not blown away; (3) their seeds have sufficient vitality for sending their tap-roots through 4-10 cm. of dry sand to the moist sand below; and (4) their aerial parts are low, radiately branching or bushy, narrow-leaved, and frequently succulent. In other words, the plants of this association are subjected to the severest kind of xerophytism. Such a habitat, hydrophytic beneath the surface of the ground and xeropyhtic above ground, is termed dissophytic by Clements.

Development.—In the Beach area the middle beach, to use Cowles' term, exists in two modifications. Towards the southern end, it is highest at the boundary line separating it from the lower beach, from which it slopes very gradually down to the fringing dune—a slope of but a few centimeters at most. Towards the north the narrow middle beach slopes upwards and abruptly gives way to the much higher (2-4 meters) fringing dune. Here the middle beach is subject to continual removal of its sand by the prevailing westerly winds. As the winds are in the westerly half of the compass much more than half of the time, the formation of extensive or high dunes is impossible on account of the lack of sand. The replenishment of the sand of the middle beach takes place during the easterly storms, of which there are but a few each year. Such storms, as a rule, are accompanied by precipitation, which further retards their power of bringing up sand from the lake. One may judge of the amount of sand that such a storm may pile up by the effects of the storm of July 30-31, 1908, in which the wind was east for a day and a half. A ridge some 20 meters wide and 0.4 meters high was piled up in front of the mouth of the Dead River, completely closing the channel—6 meters wide and 0.5 meters deep—which that river had had the day previous. And this does not begin to compare with the amounts blown up on the southern and eastern shores of Lake Michigan. Some sand is blown up during the winter unless the shore is ice bound. At that season there is a noticeable transfer of sand from the northern parts, where it is held by the season's vegetation, towards the southern parts, where north of the Waukegan piers it is building the shore out into the lake.

The southern part is more wind-swept because protected on the landward side by only a very low (at most 0.2 meters) fringing dune. It is characterized by extreme openness of vegetation. The

plants that occur, always at very widely separated intervals, are seaside spurge (*Euphorbia polygonifolia*), cocklebur (*Xanthium commune*), and sea rocket (*Cakile edentula*), in abundance as named. Each of these plants has to contend with a continual exposure of its root system by the removal of sand. *Euphorbia polygonifolia* usually escapes this by living in depressions. If growing on the level, however, it forms a dense mat which holds the sand within its compass, building up a miniature dune about two centimeters in hight and sometimes twenty centimeters in diameter. (See Plate XLV, Figure 1.) If the blowing is too vigorous, the plants will succumb, and it is not unusual to find dead, curled-up plants of this species rolling about in the wind. There is apparently no adaptation in *Cakile* for the protection of its root system, but *Xanthium* is adapted by growing procumbent with only the apical four to seven centimeters projecting into the air. The spread of leaves around the stem aids in the formation of a small, temporary dune which protects the root system from exposure. Even then plants have been found in which there was a distance of 6-10 cm. from the exposed bur, from which the plant had germinated, to the point at which the root was covered with sand. This indicates that considerable sand had been removed.

Pieces of driftwood on the beach are often the starting points for small, temporary dunes. Occasionally a plant of *Xanthium commune* will fix such a dune for a season. In the vicinity of Beach, where the middle beach is very narrow and protected by the fringing dune, the characteristic plant is *Euphorbia polygonifolia*. This plant is most abundant where there are pebbles to afford it protection from the wind. *Cakile edentula* occurs only at rare intervals, while *Xanthium* is virtually absent.

During the season of 1910, which was characterized by the extreme duration of a protracted drought, the water-level of Lake Michigan was very noticeably lowered. This made the wave action on the ground occupied by this association virtually nil. In addition to a normal abundance of the usual dominant species, there were the following secondary plants, whose growing habits were somewhat similar to those of the dominant species: *Cycloloma atriplicifolium*, Russian thistle (*Salsola kali tenuifolia*); bug-seed (*Corispermum hyssopifolium*), cottonwood (*Populus deltoides*), and *Salix syrticola*. All of these plants were characterized by the extreme length of their secondary roots. These spread radially from the small bushy plants, giving the plant command of the water supply from an area eight to fourteen feet in diameter. The roots were quite strong and could be easily pulled up in lengths of four to six feet. The plants themselves

seemed to be smaller and more succulent than usual, but the stems were thicker, and in the case of plants which are more or less pubescent when young the pubescence was retained and frequently developed into villousness. All of these modifications were direct results of the dryness of the summer.

LIST OF THE SPECIES OF THE CAKILE - XANTHIUM ASSOCIATION

Dominant Species

Cakile edentula	*Xanthium commune*
Euphorbia polygonifolia	

Secondary Species

Corispermum hyssopifolium	*Cycloloma atriplicifolium*

Invading species (all of which are relatively scarce and are not met with every year)

Salsola kali tenuifolia	*Salix syrticola*
Populus deltoides	*Potentilla anserina*

On the normal middle beach, only the first three of the dominant species, mentioned above, are present. North of Winthrop Harbor, however, where the ridges and swales are being washed away by the waves, several other species are found on the middle beach. Their presence is both accidental and temporary. The more frequent of such plants are blue vervain (*Verbena hastata*), mullen (*Verbascum thapsus*), sandbur (*Cenchrus carolinianus*), strawberry (*Fragaria virginiana*), white clover (*Trifolium repens*), smartweed (*Polygonum persicaria*), *Potentilla anserina, Polygonum acre, Panicum capillare, Acnida tuberculata submuda, Polygonum lapathifolium,* horsetail (*Equisetum arvense*), and sand-bar willow (*Salix longifolia*). In other places were the following additional species: blue grass (*Poa pratensis*), *Juncus tenuis,* Canada thistle (*Cirsium arvense*), *Lythrum alatum, Radicula palustris,* and red clover (*Trifolium pratense*). Although these plants occur within the limits of the *Cakile-Xanthium* association, they do not properly belong to it for the following reasons. Surrounding their roots, there is always more or less prairie humus, which is sometimes only about the individual plants. In some places there is a strip of prairie which, when undermined by the waves, slides down on the middle beach, carrying with it whatever plants are growing in it. Later, these strips are buried by a few centimeters of drifted sand. The plants usually persist through the one season but do not grow the next year. The burying process may keep up dur-

ing the season. In general this is liable to kill prairie plants within the summer, but, in a few cases, *Panicum capillare, Acnida tuberculata subnuda, Trifolium repens,* and *Salix longifolia* will keep pace with the incoming sand.

Since these species which constitute the derived element of the association can under no circumstances commence to grow on the middle beach, and since their presence there is to be accounted for solely by physical displacement of the soil upon which they were growing and has absolutely no successional value, one can not say that they are a real part of the association.

The Middle-Beach Pool Associations

In describing the middle beach (see under *Development*, page 270) it was mentioned that in the southern part of the area its slope from the lower beach was downward toward the lake-level. Just a little north of the docks at Waukegan, the beach has reached the level of sand which is permanently moist clear to the surface. Standing water is not usually present throughout the season, and so the beach pool is not permanent. This is the situation to which three groups of plants give such a definite floristic character that they must be termed associations, small in area and isolated though they are. In genetic order these are the *Juncus alpinus insignis,* the *Triglochin palustris,* and the *Carex oederi pumila - Cyperus rivularis* associations. These groups of plants are not of frequent occurrence in this region. Although they usually occur isolated from one another, they show sufficient successional relationships to indicate that they are three associations, rather than consocies of one association as Jennings (1909: 352) treated them.

The Juncus alpinus insignis Association

The lowest of these associations, the *Juncus alpinus insignis,* has been found in typical form only in exceptionally dry years, such as 1908 and 1910, when it occupied the dried-up bottoms of beach pools. This *Juncus* grows in small tufts, thoroughly dominating the association. With it are seldom any secondary species, and when they do occur they are of very minor importance.

List of the species of the Juncus alpinus insignis association

Dominant Species	Secondary Species
Juncus alpinus insignis	*Bidens vulgata*

Invading Species	
Scirpus americanus	*Triglochin palustris*

THE TRIGLOCHIN PALUSTRIS ASSOCIATION

This association is present every year. It normally occurs along the margins of the beach pools or in moist sand in other depressions. The individual plants of the *Triglochin,* which comprise about 70 per cent. of the area, grow close together in small tufts. The tufts themselves are separated by intervals of two to three to ten centimeters. Toward the landward side, where the tufts are still farther apart, the secondary species of this association occur. They are pioneers of succeeding associations, the most important of which is the *Juncus balticus littoralis,* which grows in higher ground than does the *Triglochin.*

LIST OF THE SPECIES OF THE TRIGLOCHIN PALUSTRIS ASSOCIATION

Dominant Species	Relic Species
Triglochin palustris	*Juncus alpinus insignis*
Invading Species	
Juncus balticus littoralis	*Juncus torreyi*
Potentilla anserina	*Scirpus americanus*
Populus deltoides (a few small seedlings under 12 cm. high)	*Cyperus rivularis*

THE CAREX OEDERI PUMILA - CYPERUS RIVULARIS ASSOCIATION

This association occupies a still higher position on the beach than the preceding one. It occurs around beach pools, but is more likely to be found in swales between the ridges than on the lake beach itself. Wherever it occurs, it is characteristic of moist rather than wet sand. It is usually submerged for a time in spring, but the ground becomes dry by the beginning of summer. This association is characterized during the different seasons by well-developed aspects. Throughout the aspects, plants belonging to the sedge family are the dominant species; *Carex oederi pumila* in late spring and early summer, *Rynchospora capillacea leviseta* during the serotinal season, and *Cyperus rivularis* during the fall. Secondary species are somewhat more numerous in point of numbers than in the two previous associations. Most of them are invaders of the different associations that may follow this one.

LIST OF THE SPECIES OF THE CAREX OEDERI PUMILA-CYPERUS RIVULARIS ASSOCIATION

Dominant Species

Carex oederi pumila
Rynchospora capillacea leviseta
Fimbristylis castanea
Ranunculus sceleratus
Cyperus rivularis
Carex aurea
Eleocharis acuminata

Relic Species

Triglochin palustris

Invading Species

Potentilla anserina
Juncus balticus littoralis
Linum virginianum
Salix syrticola (small plants)
Lobelia kalmii
Utricularia cornuta

THE SABATIA-LINUM ASSOCIATION

Immediately above the preceding association and sending out many invaders into it, is the *Sabatia-Linum* association, which is almost the exact counterpart of that found by Jennings (1909:355) on Presque Isle. One of the dominant species of this association, *Sabatia angularis,* occurs in the general region around the head of Lake Michigan, but is locally absent in the Beach region. The presence of this association is usually an indication that a given area of ground will be occupied by prairie rather than by forest associations.

LIST OF THE SPECIES OF THE SABATIA-LINUM ASSOCIATION

Dominant Species

Linum virginianum

Secondary Species

Lobelia kalmii
Utricularia cornuta
Aster ptarmicoides
Carex crawei
Gentiana procera (small plants)
Campanula aparinoides
Spiranthes cernua
Gerardia paupercula
Liparis loeselii

Relic Species

Eleocharis acuminata
Rynchospora capillacea leviseta
Carex oederi pumila
Carex aurea

Invading Species (of relatively frequent occurrence)
Juncus balticus littoralis

Invading Species (of rather rare occurrence)

Salix longifolia	*Panicum* sp.
Salix glaucophylla	*Arctostaphylos uva-ursi*
Salix syrticola	*Petalostemum purpureum*

THE JUNCUS BALTICUS LITTORALIS ASSOCIATION

One of the first indications of the first type of upper beach, as Cowles (1899:167 et seq.) terms that part of the beach which is entirely without wave action throughout the year, is the presence of the rush *Juncus balticus littoralis.* It grows from straight rhizomes which may be over three meters in length. The lines of plants cross and recross each other in every direction. Expansion on the landward side is ecologically impossible because of the closed association behind it. Progress out on to the middle beach is limited only by the action of the waves in winter and by the winds which keep uncovering the outermost rootstalks. As the lines grow outward the shifting sand is retained around the bases of the plants. It may even form embryonic dunes to the hight of a few centimeters. This work, however, is nearly always destroyed when the westerly winter winds, with nothing to impede them, carry the sand back into the lake. The *Juncus* itself does not seem to be able to fix the dunes, but it is a pioneer that enables dune-fixing plants to gain a foothold on a low and level beach like that which, in the southern part of this area, extends from Beach to Waukegan. There is no *Juncus* where the slope of the shore is 15° or more. The lakeward side of this association is composed of just the one species, *Juncus balticus littoralis.* In the middle and in the landward side other plants appear. The most abundant of these is silverweed (*Potentilla anserina*), of which more will be said in connection with the following association. Small straggling plants of *Salix syrticola* occur at intervals, but as a component part of this association they are not well developed. Occasionally a dwarfed, small-leaved plant of cottonwood, *Populus deltoides,* may be seen. Because of the deficiency of nutriment in the soil the cottonwoods grow very slowly—sometimes not more than a couple of centimeters in a season. *Scirpus americanus* occurs here more frequently than in the *Triglochin palustris* association, but still is not abundant. It has a remarkable tendency to grow in a spiral form when it grows in the sand.

The *Juncus balticus littoralis* itself possesses this tendency, but to a less marked degree. The presence of the *Scirpus* is conclusive proof that wet sand is close to the surface.

LIST OF THE SPECIES OF THE JUNCUS BALTICUS LITTORALIS ASSOCIATION

Dominant Species

Juncus balticus littoralis

Relic Species

Triglochin palustris
Cakile edentula
Cycloloma atriplicifolium

Invading Species

Potentilla anserina
Salix syrticola
Populus deltoides
Elymus canadensis
Scirpus americanus

In addition to the part that the *Juncus* plays in building up the beach, it has an important rôle in retarding the storm waves in their attack on the shore-line between Kenosha and Winthrop Harbor. Its efforts are only partially successful as Figure 1, Plate XLVI, illustrates. The relic dune* (A) in the center of the figure and the two at the left, mark the limits of the grassy sand plain in 1905. This plain is usually separated from the lake by a very dense growth of *Juncus balticus littoralis*. The width of this *Juncus* association is from one to three meters. It is separated from the grassy plain by a narrow tension zone of *Potentilla anserina*. The interwoven mass of rhizomes of the *Juncus* protects the sand from sliding. As a result there is normally a perpendicular bluff of 1.0 to 1.4 meters' elevation at the lake. Repeated buffetings of the lake wear through the *Juncus* in spots. This affords an opening to the grassy plain behind, with which violent waves make short work. The limit of the wave action is due to the loss of power to move sand after the waves have proceeded over a stretch of beach. The retreating waves carry back with them sand from the rear of the *Juncus*. After about four years of such action the beach line has the appearance shown in Figure 1, Plate XLVI. In the center of the figure is a relic dune. Its elevation above the water is the same as that of the grassy plain in the foreground. This is illustrated by Figure 2, Plate XLV. The sides of these relic dunes

*Gates, F. C. Relic Dunes, A Life History. Trans. Ill. Acad. Sci., Vol. III, 1910, pp. 110-116.

are coated with a dense mat of exposed rhizomes of *Juncus*. At "C" in the figure is a *Juncus* dune in one of the stages of obliteration.

The flora of these interesting relics is very uniform. *Juncus balticus littoralis* is the characteristic species and occupies 95 to 99 per cent. of the area of the caps in Figure 1, Plate XLVI. The following are infrequent in their occurrence and irregular in their distribution: evening primrose (*Oenothera rhombipetala*), Russian thistle (*Salsola kali tenuifolia*), sandbur (*Cenchrus carolinianus*), silverweed (*Potentilla anserina*), *Sporobolus cryptandrus,* dogwood (*Cornus stolonifera*), and *Calamovilfa longifolia.*

Proceeding southward from the portion shown in Figure 1, Plate XLVI, the shore-line begins to curve somewhat to the west and is not subject to so much wave action. The rifts in the *Juncus* association become less frequent and of less and less importance as the shore dips away from the direct attack of the waves. The sand is piled at the base of the *Juncus rhizomes* so that the bluff is concave. The association still contains over 90 per cent. of *Juncus balticus littoralis,* but secondary species are a little commoner and more sandbur (*Cenchrus carolinianus*), *Cornus stolonifera, Ptelea trifolia,* Canada thistle (*Cirsium arvense*), *Oenothera rhombipetala,* and balm of Gilead (*Populus candicans*) are present.

Besides characterizing an association, *Juncus balticus littoralis* grows in a majority of the other associations of the Beach region. It will be given consideration accordingly under them. Notwithstanding its apparent disregard for habitat it rarely shows any modifications in form in the habitats in which it is evidently a relic.

THE POTENTILLA ANSERINA ASSOCIATION

From the *Juncus balticus littoralis* association the sand slopes up gradually to the *Salix syrticola* or fringing-dune association. This slope is characterized by a rather dense growth of low plants of which silverweed (*Potentilla anserina*) constitutes from 70 to 90 per cent. It may be termed a tension-line association, and separates very distinctly the fringing dune from the *Juncus* association. *Potentilla anserina* grows in each of the three associations, but it shows its maximum development in the *Potentilla* association. In the bordering associations the size of the individuals varies to a minimum and their number to zero.

Potentilla anserina spreads very rapidly by means of runners which radiate from the parent plants. At quite regular intervals of from one to two decimeters each runner sends out roots and leaves.

The new growth decreases in size with increasing distance from the center. Any accident received by the runners causes separation into independent plants, from which new runners may extend. *Potentilla* can not contend with the wind. It is rather easily killed, either by sand being blown away from its roots or by being buried in drifting sand. In the spring, before there is a carpet of vegetation over the ground, the young plants are to some extent protected from the wind by the bushes of *Salix syrticola* and the dead stems of *Juncus balticus littoralis*. Once a carpet is formed, there is little danger of damage from the wind.

If protected from wind and still connected with the parent plant, runners may proceed through rifts in the *Juncus*, out upon the middle beach, where they may develop roots and leaves in the usual way but of smaller dimensions. During the season of 1908, when there was an unusually small number of heavy winds, many long runners developed in this way. A number of them were severed, resulting in the gradual starvation of the young plants, thus isolated upon the middle beach. This was probably due to the deficiency of food material there—a fact which has often been commented upon. The season of 1909, with its heavy surf and strong wind storms, prevented any such development of runners.

The secondary species of this association are not many in either number of species or of individuals. Without exception they are obviously under the usual size. This also is due to the lack of nourishment in the sand. The commonest of these species is *Juncus balticus littoralis*. A few *J. alpinus insignis* occur as relics where the *Potentilla* has successfully invaded the *Triglochin palustris* association. The *Triglochin* may also remain as a relic but it is less liable to persist.

LIST OF THE SPECIES OF THE POTENTILLA ANSERINA ASSOCIATION

Dominant Species

Potentilla anserina

Secondary Species

Juncus balticus littoralis (which is also a relic)

Relic Species

Juncus alpinus insignis
Triglochin palustris

Invading Species

Salix syrticola
Calamovilfa longifolia
Panicum virgatum
Populus deltoides (1-2 dm. high)
Salix longifolia

In beaches which are being destroyed, such as the region between Winthrop Harbor and Kenosha, a narrow tension association of *Potentilla anserina* separates the grassy plain (*Poa compressa* association) from the very low ridge of a very dense growth of *Juncus balticus littoralis*. In the course of the destruction of the shore, as has been mentioned above, there is exposed an area of open sand between the sand-plain and the relic dunes. (See Fig. 1, Plate XLVI.) For the most part, this area is devoid of plants but in slightly sheltered places, *Potentilla* comes in and spreads out radially, forming mats a few meters in width and several meters in length. The leaves are usually half buried and the runners can scarcely keep above the sand. It may be for this reason that here the internodes of the runners are so short. With it are seldom any secondary species. At the edge of the grass on the sand-plain (Fig. 1, Plate XLVI) is a well-developed association of *Potentilla,* and mixed with it are *Sporobolus cryptandrus* and sandbur (*Cenchrus carolinianus*). This makes a denser vegetation during the growing season than the grassy sand-plain itself shows, and effectually prevents any blowing during that period, thus protecting the grassy plain. During the winter, when the sand is rendered mobile with the drying of the *Potentilla,* a general southward movement of the sand takes place in sufficient quantities to be noticed from year to year.

The Dune Formation

Landward from the beach formation occurs the dune formation. This has been so frequently and so well described, (e.g., Cowles, 1899), that only a brief summary of the characteristics need be given before dealing with the associations. The essential conditions for dunes are wind, dry mobile sand, and a nucleus to allow the sand to accumulate (cf. Warming, 1909:263).

Ecological Characteristics.—(Cf. Cowles, 1899:106-111). The sand-dune is a very xerophytic habitat because of the agencies that increase transpiration and at the same time keep down the water supply, such as intense light and heat and strong winds. The water supply for sand-dune plants is deficient because water passes through sand very readily and but a small amount is retained in it. To this may be added the low nutritive value of the sand. On account of the insolubility of the sand grains and the easy access of air, organic matter which otherwise would form humus is rapidly oxidized. Water continually passing through the sand washes away even the less soluble food constituents (Livingston, 1903:14). A sand-dune, how-

ever, is not dry throughout. The sand to within a few centimeters of the surface is moist. The layer of dry sand which acts as a very good non-conductor of heat prevents the entire desiccation of a dune. Because of this, vegetation there is possible.

Adaptations of the Vegetation.—The characteristic adaptation of sand-dune plants is found in the extreme development of the root system in comparison with the aerial parts. To meet the constant shifting of the sand, which may uncover the roots, they are capable of producing adventitious shoots. Because of this, the plant can sometimes move a considerable distance in keeping pace with the sand. Sand-dune plants usually cover quite a little ground, and thus protect themselves from exposure of their roots because of the blowing sand. The grasses that inhabit the dunes are perennials, and they are frequently tufted. The mere presence of some of these grasses on the upper beach may often be the starting-point of a dune.

The aerial parts are clearly developed in response to the extremely xerophytic habitat. The leaves are firm in texture, with stomata well protected by the position of the leaves or by a protecting covering of hairs. Often the leaves are long and narrow and curled or folded to reduce transpiration. The inflorescence is frequently protected in the upper sheaths until it is virtually fully ready for pollination.

Plants as Dune Builders.—(Cf. Cowles, 1899:175 et seq.) Plants may live on a dune and yet add nothing to the life of a dune. They will accumulate sand during a season and form miniature or embryonic dunes, but as soon as the plants die down in autumn the sand is again mobile. Such dunes very seldom last during the winter, although many of them are formed during the growing season. They are the "annual dunes" of Cowles (1899:177). To endure from season to season a dune must be fixed by perennials, particularly of the group known as sand-binders. It is well known that owing to the persistence of the vegetative parts in winter such plants have considerable ability to prevent sand from shifting. For a dune to grow larger the sand-binder must be able to respond easily to changing conditions; and it must not be killed by exposure of its root system nor by the burial of its stem. To make the dune more extensive it must be able to spread radially by rhizome development, thus developing the dune in expanse at the same time that the upward growth of the stems is developing it in altitude.

Location in the Beach Area.—The sand-dunes occur a little beyond the limit of winter wave-action. They are more general in occurrence and better developed in constructive beaches. Nowhere in

this region are sand-dunes well developed. This is because the prevailing winds are westerly, while the lake, from which the sand must come, is to the eastward of the beach. The largest dunes are about four meters high. They are protected from westerly winds by woods of pine or oak. Towards the northern and southern parts of the area, where there is no protection from winds, the dunes are seldom more than four decimeters in hight. All but one of the dunes in the area are fixed dunes, either permanently or for a season only. Traveling dunes, such as occur along the southern and eastern sides of Lake Michigan, are absent because the prevailing westerly winds merely take away any loose sand and carry it back into the lake. The one traveling dune is nine meters high, and is protected from westerly winds by oak woods. In order to have any permanent dunes whatsoever the sand must be fixed by vegetation.

The Dune Associations

The different dune-forming plants give a more or less characteristic apearance to the dunes on which they occur. The dune-former is the all-important plant in the dune associations. Only a very few other species are capable of withstanding such a severe habitat, and as a consequence the dune associations are poor in species. As soon as the pioneer species begin to accumulate humus, invaders appear and assume possession, while the pioneers advance onward, in general, towards the lake. The process is, however, very slow, and is greatly hindered by severe wind storms and tidal waves.

Dune associations are usually independent of one another, and the dune complexes are built up in part by the growth of individual dunes. When this occurs, succession takes place which leads to the formation of the climax dune vegetation, as the juniper dunes may be designated.

The Calamovilfa Dune Association

The sand-binding grass, *Calamovilfa longifolia,* plays the most important part in initiating new dunes on the upper beaches. This grass is a most efficient sand-binder, and it will commence its growth under more adverse conditions in this region than will any of the others. The root system is extensive and forms a very dense tangle, as shown in Figure 1, Plate XLVIII. This plant always grows in tufts, and as soon as the leaves appear sand begins to be caught around the stems and lower leaves. The dune soon takes the shape shown in Figure 2, Plate XLVII. From the windward side the dune

slopes quite gradually up to the highest point in the center of the clump, from which the slope is more gradual down to the leeward. After severe wind storms the leeward trail may be over a meter in length. A change of wind, however, soon changes its position.

During the winter the dead standing stems with their leaves protect the dune in a measure from ordinary winds and storms. On the more open upper beach this protection is inadequate, and the return of the growing season finds the sand level with some exposed roots to show the former location of the *Calamovilfa* dune. But a short time is needed to reconstruct the dune when the growing season is once commenced. In less exposed situations the dunes persist over winter.

The *Calamovilfa* dunes are a conspicuous feature of the vegetation of the lake shore in the central part of the region, yet the dunes are never large in size. They spread radially quite easily but they do not grow very much in hight. A *Calamovilfa* dune a meter high is uncommon. The usual altitude is from three to six decimeters. Higher dunes are formed by plants whose ecesis can be accomplished in a *Calamovilfa* dune but could not have been on the normal upper beach.

The outcome of the growth of these dunes is usually the formation of a ridge running parallel with the line of wave action. As additional ridges are built up nearer the lake, the *Calamovilfa* remains as a relic along the crest of the ridge. In such places it sometimes exhibits the growth form known as fairy rings. Succeeding associations, however, finally bring about its disappearance. The secondary species of this association are very few in number and, in general, unimportant in value.

LIST OF THE SPECIES OF THE CALAMOVILFA DUNE ASSOCIATION

Dominant Species

Calamovilfa longifolia

Invading Species

Andropogon scoparius
Prunus pumila
Elymus canadensis
Salix glaucophylla
Populus candicans
Petalostemum purpureum f. *arenarium*
Quercus velutina (rarely)
Vitis vulpina (one plant, 3.5 meters long)

THE AMMOPHILA ARENARIA DUNE ASSOCIATION

Because there is so little sand carried from the lake, this association of dune plants is very scarce in this region. *Ammophila arenaria*

is a plant that grows best where there is an abundance of blowing sand. In such situations it builds dunes to a hight of several meters. In this region the *Ammophila* dunes are in no case more than a meter high. The dune has a very gradual slope, which is steeper on the landward side. The plant spreads in lines and does not form clumps as *Calamovilfa* does. *Ammophila* exceeds all other sand-binding grasses in the ability to grow upwards with the accumulation of the sand. At the same time the aggregation is so open that, in this region, it permits the sand to be carried back into the lake almost as fast as it is accumulated by the plant. This is the exact reverse of conditions prevailing in the *Calamovilfa* dunes, where the close bunching of the grass and the usually persistent dead leaves at the base of the stem permit a more prominent heaping up of the sand.

Ammophila dunes are pioneers of upper beach vegetation, but they will not commence so near the drift beach as will the *Calamovilfa*. On the other hand, *Calamovilfa* can capture the *Ammophila* dunes and replace the plants by which they were formed.

The *Ammophila* dune association is so poorly developed in this area that an adequate description of it is not possible from the data at hand. An extended description is given in a paper by Cowles (1899:179-181). The secondary species that occur have scarcely anything to do with the growth of the dune. They merely represent beach species whose seeds have lodged among the *Ammophila* stems. *Lathyrus maritimus*, the beach pea, is the most abundant and best developed. Its procumbent stems trail in and out between the *Ammophila* stems for several decimeters. Like the other secondary species, it occurs just over the crest, as viewed from the lake. The main part of Figure 2, Plate XLVIII, is occupied by an *Ammophila* dune.

LIST OF THE SPECIES OF THE AMMOPHILA DUNE ASSOCIATION

Dominant Species

Ammophila arenaria

Secondary Species

Calamovilfa longifolia
Lathyrus maritimus
Potentilla anserina

Relic Species

Euphorbia polygonifolia
Xanthium commune

Invading Species

Calamovilfa longifolia
Prunus pumila
Salix longifolia
Solidago graminifolia

THE SALIX SYRTICOLA DUNE ASSOCIATION

In the southern part of the region occur the low fringing dunes which are tenanted by the willow, *Salix syrticola*. They are low flat dunes, just a little out of the reach of the winter storms. They tend to grow in width rather than in hight, and consequently this association is one of the first to make a permanent vegetation on the beach.

The plant itself grows as a straggly bush, sufficiently dense, apparently, to cover the ground with vegetation but not to prevent a strong wind from carrying away sand that may have accumulated at the bases of the stems. Because of this the hight of these dunes depends upon the amount of protection that they have from the westerly winds. From Waukegan to the area of the pines, where there is no such protection, the *Salix syrticola* dunes are from two to four decimeters in hight. When protection is afforded by the pines the dune will keep pace with the blowing sand to a hight of about three meters. Only a few plants of this willow, however, are able to continue their growth upward with the accumulating sand, and the ridge is broken up into a dune-complex in which only a few of the dunes belong to this association.

At the southern end of the area, where the beach is low and very level, seeds of this willow germinate in the *Juncus balticus littoralis* association. The plants are larger in the *Potentilla* association, and reach their average development in size on the low ridge just back from it. This ridge is the typically developed *Salix syrticola* dune. In this part of the region occur the majority of the secondary species, virtually all of which are relics or invaders.

A little farther north where the beach is still level, although sloping upward all the way from the lake, the *Salix syrticola* dune, composed of the dominant species only, occupies the lakeward front. There is more blowing sand there and each plant is partly buried. The plants continue their advance lakeward as fast as they are permitted by means of their underground stems.

LIST OF THE SPECIES OF THE SALIX SYRTICOLA DUNE ASSOCIATION

Dominant Species

Salix syrticola

Secondary Species

Elymus canadensis
Salix longifolia
Populus deltoides (1 m. high)
Lathyrus maritimus (rare)
Salix glaucophylla

Relic Species

Potentilla anserina
Juncus balticus littoralis
Xanthium commune
Calamovilfa longifolia (not common; it usually occurs as a little hill, built up 1-2 dm. above its surroundings)

Invading Species

Andropogon scoparius
Solidago graminifolia
Potentilla fruticosa
Equisetum hiemalis

THE PRUNUS PUMILA DUNE ASSOCIATION

Entering into the composition of the dune-complex to the eastward of the pines are several steep mounds surrounded and capped by sand cherry (*Prunus pumila*). This plant is a very efficient dune-holder, but no examples of stages in dune formation by it were found. The occasional presence of a *Calamovilfa* at the summit indicates that, in this region at least, *Prunus pumila* dunes are formed by the replacement of a dune-originator. The fruit of the *Prunus* is eaten by a few species of birds among which are two, the song sparrow and the tree sparrow, which occasionally frequent the clumps of *Calamovilfa*. Once the *Prunus* is started, sand can be easily held by its dense growth. This is too dense for secondary species, but where there is a break, a young *Populus candicans* may be present. Occasionally on one of these dunes there is alongside of the *Prunus pumila* a bush of dogwood (*Cornus stolonifera*), which has much the same habits as the *Prunus*. The presence of the *Cornus* is due directly to birds, as this species is avevectant. The robin seems to be the most probable agent, as it has been observed eating the drupelets, and has been seen on the *Prunus* bushes while drying after a bath in the lake. The distance traversed by the dogwood amounts to nearly a kilometer.

On account of the dense growth of the dominant species, a *Prunus pumila* dune remains an isolated unit in the dune-complex. In case of the death of the *Prunus* the sand which it has held is again mobile, and a few wind storms will effect its removal.

LIST OF THE SPECIES OF THE PRUNUS PUMILA DUNE ASSOCIATION

Dominant Species

Prunus pumila
Cornus stolonifera (infrequent)

Secondary Species

Populus candicans

Relic Species

Calamovilfa longifolia (not common)

THE POPULUS CANDICANS DUNE ASSOCIATION

In a restricted area between Beach and Zion City occur the dunes of maximum hight. They are surmounted by narrow groves of balm of Gilead (*Populus candicans*). The tree trunks show no evidence of being buried. On the other hand, at the ends of the association there is every evidence to show that sand is being blown lakeward, and, to a slight degree, landward, upon an adjoining prairie or heath, as the case may be.

Populus candicans is a plant which facilitates the growth of dunes but it does not originate them. The plants of the dunes are all trees of average size. The young plants, when present on dunes at all, occur among other species, especially with *Prunus pumila*. By far the greater number of the young plants occur in the heath and the *Liatris scariosa* associations. There they grow, and by their shade the density of the ground flora is reduced. As this disappears sand is set free to the wind, and may then form a ridge dune. These dunes are quite similar to those found by Jennings (1909:338) on Presque Isle. There, however, it is cottonwood (*Populus deltoides*) that is the dune nucleus. *Populus deltoides* occurs in the Beach region along the margins of either permanent or temporary lagoons but the individuals are separated and do not show a tendency to become dune-formers. A *Populus candicans* dune is shown in the background of Figure 2, Plate XLVIII.

LIST OF THE SPECIES OF THE POPULUS CANDICANS DUNE ASSOCIATION

Dominant Species	Secondary Species
Populus candicans	*Prunus pumila*

THE ELYMUS CANADENSIS DUNE ASSOCIATION

Dunes of this type are infrequent and of little importance in this region. They are low (3 dm.) with a rather steep front towards the lake and a very gradual slope away from the lake. The crest is occupied by wild rye (*Elymus canadensis*) and the slope by that species mixed in with *Sporobolus cryptandrus* and *Artemisia caudata*. Westward of these dunes is an open area from which sand has been removed by man to the lake-level. The *Elymus* dunes keep the lake from flooding the area and the spring rains from running directly into the lake.

LIST OF THE SPECIES OF THE ELYMUS CANADENSIS DUNE ASSOCIATION

Dominant Species

Elymus canadensis

Secondary Species

Sporobolus cryptandrus
Euphorbia polygonifolia
Euphorbia corollata
Rhus toxicodendron
Artemisia caudata
Salix longifolia
Cycloloma atriplicifolium
Asclepias syriaca
Panicum virgatum

Relic Species

Cakile edentula

THE JUNIPERUS DUNES ASSOCIATION

When a small dune has been formed by some of the sand-binding plants, such as *Calamovilfa, Prunus pumila,* or, less frequently, *Andropogon scoparius,* either one or both of two species of *Juniperus* may come in and replace them, forming what is called the juniper dune. Bearberry (*Arctostaphylos uva-ursi*), a heath plant, may be present, but in this region it shows a preference for the sides rather than the crests of dunes. These plants, *Arctostaphylos* and the two species of *Juniperus,* seldom intermingle but form adjoining families in the same association. There seems to be no evidence as to which juniper appears on a dune first. *Juniperus horizontalis,* however, is by far the more abundant on the dunes, although *Juniperus communis depressa* is just as well developed. It is characteristic of juniper dunes to have the sides as well as the crest densely matted with vegetation. *Juniperus horizontalis* is especially adapted for this (see Pl. XLIX, Fig. 1). Its prostrate stems form a dense matwork of vegetation in both winter and summer, which retains considerable sand. The junipers themselves easily keep pace with the infiltration of sand, and by growing outwards permit the dune to grow radially at the same time that it is growing in hight. This figure shows a place where the wind is demolishing the dune. The *Calamovilfa* which appears midway at the left was carried there when the crest gave way to undermining. These dunes reach an altitude of three to four meters. Higher growth is difficult because most of the sand-blowing winds are parallel to rather than at right angles with the axes of the dunes.

Juniperus communis depressa dunes are less frequent and more gently sloping than those of *Juniperus horizontalis.* Their sides are

much more frequently blown away by the wind. In view of this, unless the sides are fixed with *Juniperus horizontalis* or *Arctostaphylos*, a *Juniperus communis depressa* dune is liable to be blown away, thus forming a break in the line of dunes through which the wind carries sand on to the heath behind them. At the same time, adjoining dunes of *Juniperus horizontalis* are undermined until the exposed side becomes covered with vegetation.

The junipers are the most efficient dune-builders in this region, but they can build dunes only where their westward side is protected from the prevailing winds. Normally the junipers are mat-formers in the heath association, which will be considered later, but in the presence of blowing sand they meet the change of condition by becoming dune-builders. These dunes must be closed associations, since any open place on them would be seized upon by the wind and the removal of the dune effected. The vegetation being dense and completely covering the ground, secondary species, with the exception of relics on the crests, do not occur. Of these relics, which were the nuclei about which the dune originated, *Calamovilfa* is the most frequent, with *Prunus pumila* second, and a very few plants of *Andropogon scoparius* and a single one of *Cornus stolonifera.*

LIST OF THE SPECIES OF THE JUNIPERUS DUNES ASSOCIATION

Dominant Species	Relic Species
Juniperus horizontalis	*Calamovilfa longifolia*
Juniperus communis depressa	*Prunus pumila*
Arctostaphylos uva-ursi	*Andropogon scoparius*
	Cornus stolonifera

Miscellaneous Dunes

In addition to the associations given above, which occupy about 97 per cent. of the dune areas, there are isolated dunes, each one of which is characterized by a rather definite association of plants. In each case the plants are more typical of other associations, but they grow within the range of blowing sand and consequently dunes may be formed around them.

THE POPULUS-SALIX DUNE ASSOCIATION

But two well-marked examples of this dune association, which has been described from Presque Isle by Jennings (1909), occur in the region. In both cases the dunes are low and are formed on the east-

ern border of the bunch-grass prairie, to be described later. One of these dunes was occupied by the following species: cottonwood (*Populus deltoides*) (2 meters in hight), *Salix glaucophylla, Salix syrticola* (a relic), *Calamovilfa longifolia,* and *Potentilla fruticosa.* The other example had the following plants: *Salix syrticola, Juncus balticus littoralis, Elymus canadensis, Salix longifolia, Populus deltoides,* and *Potentilla anserina.*

Once in a while a well developed *Salix glaucophylla* or *Salix longifolia* will form miniature dunes. The branches bend down to the ground, and beneath their shelter sand and debris gradually accumulate. In the debris are seeds of various plants, notably the winged ones of species of *Populus* and *Salix.* In rifts where sufficient light may be had, a number of plants which could not obtain a foothold on the open sand may get a start. The following species were observed: strawberry (*Fragaria virginiana*), rock cress (*Arabis lyrata*), fleabane (*Erigeron philadelphicus*), silverweed (*Potentilla anserina*). *Panicum virgatum, Artemisia caudata, Zizia aurea,* touch-me-not (*Impatiens biflora*), dandelion (*Taraxacum erythrospermum*), and sweet clover (*Melilotus alba*). Seedling *Populus deltoides* were also present, which indicates that a *Populus-Salix* dune is being formed. *Populus deltoides* itself when growing on sand in this region does not form dunes. Species of *Salix,* which afford a ground protection to retain sand, at the same time serve to catch *Populus* seeds. Normally a thicket should be formed, but as yet the ground is too poor in food materials to support the mesophytic species of the thicket association.

THE SALIX GLAUCOPHYLLA DUNE ASSOCIATION

A few dunes formed entirely by this plant were observed near Kenosha, one of which is shown in Figure 2, Plate XLIX. The dunes are low and elliptical in shape, while the major axis, which runs north-northwest, is about twice as long as the minor axis.

THE PANICUM VIRGATUM DUNE ASSOCIATION

During the growing season a small dune may be built up around a tuft of *Panicum virgatum,* but such dunes are temporary, as they do not withstand the winter. As a rule these dunes have no other species than the *Panicum* upon them, but occasionally *Arabis lyrata, Salix syrticola, Poa compressa* and *Poa pratensis* occur around the edges of the tuft of *Panicum.*

THE ANDROPOGON SCOPARIUS DUNE ASSOCIATION

This grass normally grows on level ground, but it may come in on the sides of dunes originated by sand-binders such as *Calamovilfa*. With the death of the *Calamovilfa, Andropogon scoparius* is left in full possession. It is efficient in holding the dune, but further growth of the dune ceases. Such dunes are at most five decimeters high.

Near Waukegan, in a place where sand has been freed from gravel, there was left a gravel mound about two meters high. The summit and nearly all of the sides are tenanted by *Andropogan scoparius* stools, in the interstices of which are several sand plants, as, for example, *Arabis lyrata, Petalostemum purpureum* f. *arenarium, Lithospermum gmelini,* etc. It has the general appearance of a developed dune, such as Jennings has described from Presque Isle, but the manner of its origin was evident.

THE POPULUS-SALIX-CORNUS THICKET DUNE ASSOCIATION

This dunelike condition exists near the state line where the lake is attacking the shore. It is not a developed dune, but the result of sand being blown in upon the *Populus-Salix-Cornus* thicket which is being cut into by the lake. The thicket reacts to the inblowing sand, however, by becoming a dense mass of liana-entwined vegetation with an advance-guard of *Salix longifolia* to check the advancing sand. Such thickets are well nigh impassable on account of the network of lianas, which in this area are wild grape (*Vitis vulpina*) and Virginia creeper (*Psedera quinquefolia*). Sand-bar willow (*Salix longifolia*) easily keeps pace with the blowing sand, but succumbs to the violence of wave action as the shore is gradually washed away. With the *Salix longifolia* are associated a few prairie plants, the roots of which are in sod buried beneath the sand. A few of the commonest are loosestrife (*Lythrum alatum*), *Panicum capillare,* white clover (*Trifolium repens*), blue vervain (*Verbena hastata*), mullen (*Verbascum thapsus*), *Polygonum lapathifolium,* sandbur (*Cenchrus caroliniamus*), and Canada thistle (*Cirsium arvense*), which in this and other places forms small dunes five to six centimeters in hight.

THE BETULA ALBA PAPYRIFERA DUNE ASSOCIATION

But two examples of this kind of a dune occur in this area. The sides are very steep and are effectually protected by a small grove of seedling trees of white birch.

RELIC DUNES*

Dunes form one of the typical stages in the construction of beaches and they may also be one of the stages in the destruction of a vegetated beach, when they may be termed "relic dunes." (See group of dunes, Pl. XLVI, Fig. 1.) The vegetation north of Winthrop Harbor is bordered on the lakeward side by a low ridge which supports a very dense growth of *Juncus balticus littoralis*. When the lake begins to cut into the beach it washes away sand from the *Juncus*, leaving an exposed bluff of densely intertangled roots. In weak spots the waves are able to wash their way entirely through the ridge of *Juncus* to the grassy plain beyond, which is easily destroyed as far as the waves have power. In places the *Juncus* is left as a mound with its sides perpendicular and densely coated with exposed roots. This is an early stage of a relic dune. (For such dune, shown in detail, see Pl. XLVI, Fig. 2.) As wave action continues, the onwash and the backwash of the waves, in combination with the wind, reduces the dune from the appearance of "A" (Fig. 1, Pl. XLVI) to that of "C," in which the sides are sloping. These summer secondary stages look very much like ordinary dunes except that they are more or less coated with exposed roots. In course of time the dune is entirely washed away. During winter the disruptive power of freezing water is an important agent in the breaking up of the dunes. The effect of a severe frost immediately following a heavy rain upon one of these dunes is shown in Figure 1, Plate XLVII.

These dunes are prominent features of the vegetation of the beach from the state line to Kenosha. With the *Juncus* are associated a few plants of relatively little importance, such as *Sporobolus cryptandrus*, Russian thistle (*Salsola kali tenuifolia*) and dogwood (*Cornus stolonifera*). Besides the *Juncus* relic dunes, there is also a single example of a relic dune formed by *Juniperus communis depressa* (see "D," Fig. 1, Pl. XLVI). Its sides are not so steep as those of the *Juncus*, and most of the vegetation is on the lakeward side. The sand that accumulates somewhat in the rear of the dune is not washed away rapidly because the dune is so near the limit of wave power. During the course of the next few decades there will be eight or ten of these *Juniperus* relic dunes, formed by both *Juniperus communis depressa* and *J. horizontalis*.

THE MAN-MADE DUNE

In order to protect the golf grounds at the southern edge of Kenosha from blowing sand, a long dune about two meters high has

*See p. 277.

been constructed and fixed by planting willows upon it. For the most part it is tenanted by species of willow, especially *Salix longifolia* and *S. glaucophylla*. The bushes form a fairly dense tangle about 1.4 meters high, and mixed with them are individuals of wild rye (*Elymus canadensis*), horsemint (*Monarda punctata*), butter and eggs (*Linaria vulgaris*), wormwood (*Artemisia caudata*) and yarrow (*Achillea millefolium*). In a few places the dune is fronted by *Juncus balticus littoralis*. Upon the west side of the dune the sodded ground extends to its base. The south end is not sufficiently well protected, and consequently the wind is undermining the willows to some extent.

THE TRAVELING DUNE

For reasons given before, this kind of a dune is not a feature of the region; in fact there is but one present in the area. Its hight above the lake-level is nine meters, and a few oaks have been partially covered by it.

The Upper Beach Associations

THE ARTEMISIA-PANICUM ASSOCIATION

This association, which is so wide-spread on Presque Isle and is of general occurrence along the shores of Lake Michigan, is but poorly represented in this region. A majority of the species mentioned by Cowles (1899:168 et seq.) occur upon it, but from 40 to 60 per cent. of the area is taken up by invading plants of the bunch-grass association, which borders and is extending rapidly into it.

Location and Physical Characteristics.—The area which stretches back from the fringing dunes, is largely composed of sand whose grains are about 0.5 mm. in diameter. The relative amount of sand decreases in going away from the lake. At the same time the relative amount of gravel increases. The change is uniform, though gradual. The *Artemisia-Panicum* association occupies the sandier parts of the upper beach, and thins out quite rapidly as the amount of gravel increases. The reverse of this is true with respect to the bunch-grass association. The sand is somewhat mobile, but not much so because of protection by the fringing dune and by the vegetation of the bunch-grass association. Water is near the surface and is easily available, but food materials dissolved in it are low in amount. The aeration of the sand, aided by the relatively large spaces between the grains and the sudden changes of temperature, is very thorough, which leads to rapid eremacausis and consequent absence of humus.

Ecological Characteristics.—Except for the absence of wave ac-

tion there is very little difference ecologically between this area and the middle beach. The habitat is dissophytic, because the underground parts of the plants are in mesophytic to hydrophytic condition according to the water content of the soil, while the upper parts are subjected to rather severe xerophytism. The desiccating effect of the wind and sun are met by adjustments in the plant structure (cf. Kearny 1900:276-280).

The Association.—The association is an open one, in which about 30 to 40 per cent. of the area is vegetated. From 30 to 50 per cent. of the vegetation is occupied by the dominant species, wormwood (*Artemisia caudata*), which gives a grayish tone to the soil. Cowles (1899:168) says that the most characteristic plants are *Artemisia caudata* and *A. canadensis*. In the Beach region, only the *A. caudata* is present. In a similar area near Rogers Park, Chicago, a few miles south, both species occur. Another dominant species, *Panicum virgatum*, which Jennings found at Cedar Point and Presque Isle, is of relatively little importance in this association in this region, although it occurs not infrequently. Its place is taken by *Sporobolus cryptandrus*, which grows in clumps somewhat like a bunch-grass. Its growth habit is illustrated by Figure 1, Plate L. This plant, however, is usually more characteristic of blowouts.

These three character species occupy about 95 per cent. of this area in typical situations of this association. Typical examples are, however, rather rare in this area. The best developed of them is about a kilometer north of the Lake County pest-house. There, this association is eight to ten meters in width and approximately twenty meters in length. Usually the invader, *Andropogon scoparius*, gives a decided character to the appearance of this association, in which it grows at intervals of two to three meters.

Of the other species which Cowles has listed as characteristic of this association, only four specimens of Pitcher's thistle (*Cirsium pitcheri*) have been found. A very few plants of beach pea (*Lathyrus maritimus*) occur here, although it is commoner on the lee slopes of the *Ammophila* dunes. A spurge (*Euphorbia polygonifolia*) is fairly abundant, although it can not be so characteristic as on the middle beach. Evening primrose, *Oenothera biennis*, does not occur in this association, and a grass (*Agropyron dasystachyum*) does not grow in the region.

Secondary species occur more or less throughout the association, but are most abundant near to the margins, where the prairie element has commenced to invade. They are not usually numerous, but frequently, because of their bright-colored flowers, seem to be nearly

dominant floristically. Such plants characterize the seasonal aspects of the association. The late-vernal and estival aspects are given by the orange flowers of puccoon (*Lithospermum gmelini*). This plant has a very long (3 or more meters), bulky tap-root, from the crown of which grow many spreading stems. It does not occur so frequently in the typical parts of the association as it does in the tension line, which the bunch-grass is rapidly pushing outwards. The serotinal aspect is characterized by the blooming of the yellow flowers of a goldenrod (*Solidago nemoralis*). This plant also is much more characteristic of the bunch-grass sand areas. The autumnal aspect is given by the blooming of *Sporobolus cryptandrus* and of *Artemisia caudata.*

In addition to those secondary species that give character to the different seasonal aspects, there are a few other species, typical of different associations, that are of importance in showing the past stages and in indicating the future successions.

LIST OF THE SPECIES OF THE ARTEMISIA-PANICUM ASSOCIATION

Dominant Species

Artemisia caudata
Panicum virgatum
Sporobolus cryptandrus

Secondary Species

Cirsium pitcheri
Lathyrus maritimus
Euphorbia polygonifolia
Lithospermum gmelini
Arenaria stricta
Cycloloma atriplicifolium
Equisetum hiemale
Arabis lyrata
Petalostemum purpureum f. *arenarium*

Relic Species

Euphorbia polygonifolia
Prunus pumila
Calamovilfa longifolia

Invading Species

Andropogon scoparius (at intervals of 2-3 meters)
Lithospermum gmelini
Arenaria stricta
Solidago nemoralis
Liatris scariosa (few)
Potentilla fruticosa
Poa compressa
Aster dumosus
Arctostaphylos uva-ursi (few)
Juniperus horizontalis (a few patches)

THE BUNCH-GRASS ASSOCIATION

The Andropogon scoparius Consocies

Location and Physical Characteristics.—Immediately westward of

the usually poorly developed *Artemisia-Panicum* association lies a more or less gravelly or pebbly area, whose vegetative appearance is characterized by the stools of *Andropogon scoparius*. The physiographic appearance gives every indication that the area was at one time part of the beach. Later it was covered with drifting sand, and it is now being gradually uncovered by the very slow movement of the fringing dune towards the lake. Because of its past history it is given the name, "fossil beach," in allusion to the corresponding geological term. The pebbles and the gravel of which its surface is composed are all well-rounded and flattened, clearly indicating the former presence of surf. The largest of these pebbles are about 15 cm. in diameter and 2-3 cm. in thickness. Almost all of them are made up of granites, quartz, and, less frequently, shales and sandstones. From between them the wind has gradually removed the mobile sand, which is taken to the lakeward side of the fringing dune. So much sand has been removed that now the pebbles are very frequently perched upon little hills a few millimeters in hight. Investigation has shown that the sand in these little "tees," to use a golfing term, is virtually damp clear to the surface. The pebble itself affords the tee protection from the drying effects of the direct rays of the sun. In the protection thus afforded, spiders as well as some small insects spend the hotter part of the day. Rain drains very rapidly through this soil.

Ecological Characteristics.—What has been said of the ecological characteristics of the *Artemisia-Panicum* association will apply here also. The habitat is dissophytic, but the above-ground part is not quite so xerophytic as in the other association. Humification—rather than eremacausis, which is the rule in the *Artemisia-Panicum* association—is beginning to take place. Lack of sufficient food material seemed to be the most potent cause for the openness of the vegetation.

The Association.—The bunch-grass association is a typical prairie one, and, of course, is better represented in areas farther west. The bunch-grass association of the prairie vegetation is the pioneer both of the prairie and the forest type of vegetation. It can maintain itself on fossil beaches and readily invades the upper beach. Meanwhile it adds humus to the soil and prepares the way for successions to a more advanced type of prairie or to a heath or to a forest. Which succeeds, depends upon several factors, among which are proximity, means of dispersal of the invaders, and the ability of the invaders to effect ecesis. The association itself has for its dominant species a grass which grows in tufts or bunches. According to the specific identity of the bunch-grass, the association is divided into

consocies. Some of these have been described for southeastern South Dakota by Harvey (1908) and for the Illinois sand areas by Gleason (1910). Of these consocies only one appears as a definite part of the region in this area. That is the *Andropogon scoparius* consocies, which has been described as a pioneer of prairie vegetation by Harvey (1908:287). There are, however, clear indications that other consocies have been represented which are now succeeded by forest associations. Some of the bunch-grasses, which were once dominant species, are now relics, living as secondary species in the *Quercus velutina* woods.

The association itself is open, since but 25 to 40 per cent. of the area is vegetated. Approximately 90 per cent. of the vegetated area is occupied by the dominant species, *Andropogon scoparius*. The secondary species may be more numerous, but they are interstitials that occupy very little surface. Figure 2, Plate L, shows the general appearance of the association throughout the year, and exhibits the manner of growth of the dominant species.

Andropogon scoparius.—As shown in Figure 2, Plate L, this grass is a typical bunch-grass. The dead leaves remain over winter and until the new leaves grow. They do not seem to be capable of retaining blowing sand, and so this grass is not a dune-former. It can fix dunes, however, but not until the dune has been built up by some regular dune-former. The plant spreads radially, but very slowly as it has no runners. The spreading continues until the diameter of the stool, or bunch, is from 3.0 to 3.5 decimeters. It does not often grow larger than this. Occasionally bunches are to be found in which the central part is dead, the circle of stems around it forming a small fairy ring. Other plants become established in the center, and tend to lead to the gradual replacement of the bunch-grass. *Arabis lyrata* and shrubby cinquefoil (*Potentilla fruticosa*), an invader, are most frequent in this rôle. Others that have been found so situated are *Arenaria stricta, Oenothera rhombipetala*, blue-eyed grass (*Sisyrinchium* sp.?), and *Artemisia caudata*. In this area the bunches themselves are always separated, usually by about eight to nine decimeters The more pebbly the area, the greater the tendency for the bunches to be nearer together, but seldom closer than five decimeters. The bunches which are invading the *Artemisia-Panicum* are developed just as well as those in the bunch-grass itself.

The area between the bunches is occupied by interstitials, which, however, are not sufficiently abundant to prevent the sand from giving the general color-tone. In point of numbers rock cress (*Arabis lyrata*) is most abundant. When it is well in bloom, in May, the

white flowers considerably lighten the general dull gray tone of the dead leaves of the *Andropogon*. This is the vernal aspect. Next to secure color prominence is *Lithospermum gmelini*, which blooms during June and July. This plant is not actually abundant in the typical part of the association, but its manner of growing and the abundance of its brilliant orange flowers are easily misleading in determining the importance of the species in the association. It is most abundant near the tension line, towards the outside of the association. Although this plant has neither dune-forming nor dune-fixing abilities, it seems most at home where this association is invading the lower parts of the dune-complex near Beach. There it occurs at frequent intervals, without apparent discrimination between the lower places and the sides of the dunes. Occasionally it is present on the tops of some of the smaller dunes. Seedlings of this species can be found in various situations, although they are most frequent in depressions. The root system of *Lithospermum gmelini* can withstand a moderate amount of either burying or uncovering, so that the plant can easily tenant the dune-complexes of the region which are protected from the westerly winds by the area of the pines. It seems to fulfill the position of pioneer to the *Andropogon scoparius* consocies of the bunch-grass association. *Cycloloma atriplicifolium*, *Petalostemum purpureum* f. *arenarium*, and *Arenaria stricta* play the same rôle, but to a less marked degree.

The estival aspect of this consocies is characterized by the blooming of the *Andropogon scoparius* itself, and of the interstitial *Petalostemum purpureum* f. *arenarium* (sand-prairie clover). The latter species, which is typically a prairie plant, exhibits marked xerophytic adaptations in several particulars—so much so that a detailed description is necessary, and it is here given in the form of a table.*

PETALOSTEMUM PURPUREUM f. arenarium FORMA NOVA.

	Petalostemum purpureum (Prairie plant)	*Petalostemum purpureum* f. arenarium (Sand-prairie plant)
Root	tap root	larger and more bulky tap root
Crown	composed of a few upright stems	composed of many (20-38) radiating stems
Stems	stout and upright	shorter, wiry, divaricate, *i. e.*, standing at an angle of less than 45° with the earth from the commencement of growth. When growing on little hillocks the stems project below the horizontal
Leaves	divaricate, lancolate-trifoliolate	appressed, linear-trifoliolate
Heads	cylindrical, larger	cylindrical, smaller relatively
Flowers and Fruit	no appreciable differences	

*This table is taken from the original description of this new form, in Torreya, 11:125-128, June, 1911.

The appearance of the sand form is very different from that of the prairie type, but the differences are due to the edaphic xerophytic conditions under which it grows. In places where this association has been succeeded by trees which have induced milder xerophytic conditions the *Petalostemum,* although still growing in nearly pure sand, is about normal in appearance. Figure 1, Plate LI shows a plant of this form in which the stems form an angle of from 5° to 15° with the sand level. In some cases sand and debris have been piled up above the crown, while sand beyond the protection of the stems has been blown away. In such places the *Petalostemum,* when growing prone, makes a negative angle with the general level. In general the individual plants grow apart, but on the gravel, where there is almost no exposed sand, they grow so close together that the heads overlap and form a tangled layer about a decimeter above the gravel level. Such situations are frequent hiding-places for savanna and song sparrows. The heads of the *Petalostemum* seem usually to be infested with a small green caterpillar, and the leaves with tent-weaving larvæ.

In the serotinal aspect, *Petalostemum* continues to dominate the more gravelly parts, but in other places a goldenrod (*Solidago nemoralis*) comes into prominence. The bright white pappus of the fruits of both *Andropogon scoparius* and *Solidago nemoralis* are characteristic of the autumnal aspect. Neither of these plants loses its seeds until after the sharp winter frosts. With the return of winter the association assumes a dull gray color of dead leaves which resembles in some particulars the arid brush-lands of the West.

List of the Species of the Andropogon scoparius Consocies of the Bunch-grass Association

Dominant Species

Andropogon scoparius

Secondary Species

Arabis lyrata
Arenaria stricta
Oenothera rhombipetala
Lithospermum gmelini
Petalostemum purpureum f. *arenarium*
Solidago nemoralis
Euphorbia corollata
Aster sericeus
Elymus canadensis
Cycloloma atriplicifolium
Hypericum kalmianum
Oenothera biennis (very few)
Prunus pumila
Aster multiflorus
Mosses (unidentified)

Relic Species

Artemisia caudata
Salix syrticola
Salix glaucophylla (not common)
Juncus balticus littoralis (not common)
Calamovilfa longifolia (as individuals rather than in bunches)
Sporobolus cryptandrus

Invading Species

Potentilla fruticosa
Sisyrinchium sp.?
Populus deltoides (small)
Salix longifolia
Juniperus communis depressa (few)
Juniperus horizontalis (few)

The Sporobolus heterolepis-Sorghastrum nutans Consocies

This consocies, which has been more widely extended in the past than it is at present, is quite similar to ordinary prairie. For the most part the consocies has been succeeded by *Quercus velutina*, but in a few places between the oak ridges there still remain small characteristic areas of it. Four bunch-grasses are its dominant species. The two after which it is named are most abundant. The others are *Andropogon scoparius* and *A. furcatus*. The largest and most conspicuous of the bunch-grasses is *Sorghastrum nutans*, which grows in tufts rather than bunches. It is, perhaps, the most persistent as a relic in the association that has followed. *Sporobolus heterolepis* itself grows in rather good-sized bunches which are usually ringlike, the open area in the center being a flat mound of blackish dirt. The stems and leaves are thin and wiry, and the plant as a whole has a rather delicate appearance. In parts of this region this grass may occupy 60 per cent. of the area. *Andropogon furcatus*, which grows in small bunches, aids in giving a general character to the area, but it is the least important of the four bunch-grasses mentioned. It seldom occupies more than 10 per cent. of the area, but it will persist under the oaks almost as well as the *Sorghastrum*. *Andropogon scoparius*, whose bunches have already been described, occupies from 30 to 50 per cent. of the area. It is smaller in size and does not give so much character to the vegetation. It grows out in the open parts of the association and, while it does persist in the *Quercus velutina* association, it does so only in the open places. In the autumnal aspect these four bunch-grasses occupy about 97 per cent. of the area, the remaining 3 per cent. being secondary species. Some of the latter are interstitials, as *Arenaria stricta*; others are grasses, as *Spartina michauxiana* and *Poa compressa*; and still others are invaders from

nearby prairies and forest, as *Potentilla fruticosa* and small plants of *Quercus velutina*. *Solidago rigida* and *S. nemoralis* occur, but not in sufficient numbers to produce the usual color-dominance. Other prairie plants occur, but very little sod is being formed. *Quercus velutina* seedlings develop readily.

List of the Species of the Sporobolus heterolepis-Sorghastrum nutans Consocies of the Bunch-grass Association

(Of the typical portion only)

Dominant Species

Sporobolus heterolepis
Sorghastrum nutans
Andropogon scoparius
Andropogon furcatus

Secondary Species

Panicum virgatum
Solidago rigida
Solidago nemoralis
Spartina michauxiana
Koeleria cristata
Aster ptarmicoides
Polygonum tenue
Amorpha canescens
Euphorbia corollata
Solidago speciosa angustata

Relic Species

Sporobolus cryptandrus

Invading Species

Quercus velutina
Liatris scariosa
Potentilla fruticosa
Lobelia spicata
Potentilla arguta
Comandra umbellata

THE LIATRIS SCARIOSA ASSOCIATION

Following the *Artemisia-Panicum* association or either of the consocies of the bunch-grass association, is another association of xerophytic plants, the *Liatris scariosa* association.

Location.—This association is found particularly upon the sand ridges farther inland than the fringing dune. It is best developed toward the southern part of the region, where it dominates the ridges of nearly pure sand. Toward the northern parts of the region the black oak has obtained dominance on the sand ridges, although the *Liatris scariosa* association may remain coexistent with it, but occupying the open spaces between the trees.

Physical Characteristics.—The soil occupied by this association is essentially sand to which a little humus has been added, though not

in sufficient quantity to change the color. The ground is protected from the lake by the fringing dune. The ridges, which parallel the bluff, are low (1-5 dm.) and usually free from blowing, but occasionally small blowouts are developed.

Ecological Characteristics.—The vegetation is essentially open, and consists mostly of upright plants half a meter or more high. Toward the sides of the ridges, where the soil contains more humus, are invaders of more typical prairie associations. The plants of this association need a maximum of light and consequently do not long withstand the shade of invading oaks. Yet the vegetation is relatively so open that the *Liatris scariosa* association forms one of the important pathways for the spreading of the oak woods. The stations of its best development are separated from the main body of the oaks by the area of the pines. The latter has acted as a partial barrier in retarding the development of the black oaks on the ridges between Waukegan and Beach.

The Association.—This association has been named from its most imposing species, blazing star (*Liatris scariosa*). This plant, with its large purplish spikes, is thoroughly dominant in the serotinal and autumnal aspects. During the estival and early serotinal seasons the white blossoms of flowering spurge (*Euphorbia corollata*) are almost equally conspicuous. A few other species of less importance are typically charcteristic of the association, such as *Castilleja sessiliflora, Liatris cylindracea,* lead plant (*Amorpha canescens*), bush clover (*Lespedeza capitata*), and black-eyed Susan (*Rudbeckia hirta*). In addition to these, almost any sand-preferring plant may be found in greater or less abundance in this association. The lines of succession leading from this association may proceed to any of the three provinces represented in this region. In the northern part of the region the succeeding association is usually the oak forest; in the vicinity of Beach it may be the heath or, to a much smaller extent, the pine woods; and near Waukegan it is usually the prairie associations, such as the *Liatris spicata,* each one of which will be described later.

LIST OF THE SPECIES OF THE LIATRIS SCARIOSA ASSOCIATION

Dominant Species

Liatris scariosa
Castilleja sessiliflora
Euphorbia corollata
Oenothera rhombipetala
Lespedeza capitata

Secondary Species

Amorpha canescens
Acerates viridiflora
Aster multiflorus
Andropogon furcatus

Aster azureus
Rudbeckia hirta
Solidago nemoralis
Panicum huachucae (in blowing sand)
Tradescantia reflexa
Liatris cylindracea
Carex umbellata
Potentilla arguta
Asclepias amplexicaulis
Silene antirrhina
Polygonum tenue

Relic Species

Koeleria cristata
Lithospermum gmelini
Panicum virgatum
Calamovilfa longifolia
Salix glaucophylla
Juncus balticus littoralis
Cycloloma atriplicifolium
Andropogon scoparius

Relic species persisting in places in which this association develops after oaks have been cleared off

Anemone cylindrica
Helianthus occidentalis
Lupinus perennis
Smilacina stellata
Hieracium canadense

Invading Species

Arctostaphylos uva-ursi
Juniperus horizontalis
Betula alba papyrifera
Potentilla fruticosa
Lobelia spicata
Linum virginianum
Aster ptarmicoides
Petalostemum candidum
Petalostemum purpureum
Comandra umbellata
Silphium integrifolium
Quercus velutina
Rhus toxicodendron
Fragaria virginiana
Asparagus officinalis (avevectant under very small *Q. velutina*)
Poa compressa

THE POA COMPRESSA ASSOCIATION

The sand-plain which stretches inland from the limit of storm wave-action, particularly from the state line to Kenosha, is characterized by a light sod of English blue grass (*Poa compressa*) rather than by blazing star (*Liatris scariosa*) or black oak. Farther inland this association may also occur on ridges from which the black oaks have been removed.

Physical Characteristics.—The ground on which this association occurs is quite pure sand, made more or less yellowish by the admixture of a substance which tends to cement the sand grains together. Occasionally there are deposits of what appears to be guano, al-

though this region is no longer a breeding place for gulls. The sand-plain is very flat, and slopes down away from the lake rather than towards it. Ordinarily the sand is fixed; but when storm waves are able to effect entrance, the sand is released and is usually blown into the lake.

Ecological Characteristics.—A comparatively thin growth of grass sufficiently dense to prevent blowing but not sufficiently dense to obscure the yellowish color of the sand, is the prevailing feature of this association. Secondary species occur here and there but are nowhere of much importance, since they occur as scattered individuals among the grass plants, which form about 90 per cent. of the area. Near the lake the grass plants are separated two to three centimeters (see foreground, Fig. 1, Pl. XLVI). On the ridges nearer the western boundary, however, the grass plants grow much closer together and form a true sod, which is usually effective in preventing further succession.

The Association.—The grass, *Poa compressa,* is the dominant species and thoroughly characterizes the association. The secondary species are, for the most part, merely sand plants which happen to become established. Some of them are relics of the *Quercus velutina* association in places where oaks have been removed, others are normal beach-plants, and several are weeds that grow readily in sandy ground. Ecesis (establishment) is not difficult for the weeds, since the ground is so open. A few species are indicative of successions. Near the lake the presence of small plants of *Juniperus horizontalis* and *J. communis depressa* look toward a heath, but in some other places the dense growth of this grass has been responsible for the dying out of the junipers. On the ridges farther inland the occasional presence of seedling trees indicates the approaching development of a forest.

LIST OF THE SPECIES OF THE POA COMPRESSA ASSOCIATION

Dominant Species

Poa compressa

The most important secondary species near the lake shore

Monarda punctata *Cenchrus carolinianus*
Sporobolus cryptandrus

Other secondary species near the lake shore

Verbena hastata *Achillea millefolium*
Erigeron canadensis *Anaphalis margaritacea*

Verbascum thapsus
Cacalia tuberosa
Panicum sp.?
Erigeron divaricatus
Poa pratensis
Rumex acetosella
Draba caroliniana
Oxalis stricta (very small plants)
Scutellaria parvula
Hypericum kalmianum
Potentilla arguta
Euphorbia corollata

Invading species living near the lake shore

Pycnanthemum virginianum
Juniperus horizontalis
Juniperus communis depressa
Lobelia spicata
Isanthus brachiatus

Secondary species in the inland areas

Rudbeckia hirta
Oenothera biennis
Euphorbia corollata
Koeleria cristata
Verbascum thapsus
Achillea millefolium
Erigeron annuus
Erigeron canadensis
Erigeron ramosus
Cyperus filiculmis macilentus
Poa pratensis
Plantago major
Rumex acetosella
Lepidium apetalum
Rosa humilis
Ambrosia artemisiaefolia
Aster dumosus
Helianthemum majus
Juncus tenuis
Oxalis stricta (dwarfed plants)
Trifolium repens
Panicum scribnerianum
Rumex crispus
Solidago serotina
Euphorbia maculata
Fragaria virginiana
Cirsium arvense
Digitaria sanguinalis
Desmodium illinoense

Relic species in the inland areas

Juncus balticus littoralis
Lithospermum gmelini
Juniperus communis depressa
Juniperus horizontalis

Invading species living in the inland areas

Lobelia spicata
Potentilla arguta
Verbena hastata
Solidago graminifolia
Allium cernuum (rare)
Aster azureus
Helianthus grosseserratus
Prunella vulgaris (much dwarfed)
Monarda mollis
Vitis vulpina
Sambucus canadensis (small)
Salix spp. (seedlings)
Quercus velutina (seedlings)
Juglans nigra (seedlings)
Carya ovata (a few seedlings)
Crataegus punctata (a few seedlings)

THE ARCTOSTAPHYLOS-JUNIPERUS HEATH ASSOCIATION

Following Warming, a heath may be defined as an area of low, evergreen vegetation. In Europe the heaths are composed mainly of ericaceous plants. In this area, the vegetative structure is similar, but the ericaceous plants play more of a secondary part.

Location.—The heath is best developed in the part of the region near Beach, where it covers what has been a dune-complex. It is becoming well developed on the present dune-complex, which is sheltered by the pine forest. Thence the heath extends south behind the bunch-grass until it disappears a little north of Waukegan. Towards the south its development is mostly in patches rather than a general condition. North of Zion City the heath exists as relic patches, of which there are but a few.

Physical Characteristics.—The heath usually appears as sandy ground almost entirely carpeted with low, shrubby, evergreen plants, such as are in the foreground of Figure 1, Plate LII. The color tone is dark green, especially in the winter. The sand is somewhat darker in color on account of the admixture with debris and humus materials.

Ecological Characteristics.—Invading heath plants are in epharmony (close accord) with the ecological conditions which they encounter. Once they become established, however, they bring about radical changes, the most important of which is the institution of humification rather than eremacausis. Blowing sand, leaves, and debris are caught and held between the branches of the heaths. For this reason, if nothing interferes, a heath is usually growing upward in hight. Although the ground is carpeted, there is still sufficient room for interstitials.

The Association.—In this area three species characterize the heath. *Juniperus horizontalis* and bearberry (*Arctostaphylos uva-ursi*) are of prime importance, while *Juniperus communis depressa* is less so. The first two are essentially mat-formers, while the *J. communis depressa* usually forms a table, elevated two to four decimeters above the surroundings. *J. horizontalis* forms large mats by growing radially. The runners, as the branches may be termed, take root at intervals. This results in a gradual movement of the whole plant. In the larger mats the central area is dead, and in some instances has given rise to blowouts. Often, however, the center may be occupied by a normally developed plant of *Juniperus communis depressa*. It is evident that this came in last because of the dead stems of the *J. horizontalis* which remain under it. A well-developed *J. communis depressa* so excludes the light that no plants will germinate or grow under it. The runners of the *J. horizontalis* send up twigs

which bear the leaves. The leaves of the season are more or less coated with a bloom which gives them a somewhat whitish appearance. The tips of the runners project into the air at an angle of about 25° to 30°. Should blowing sand encounter them a small ridge is built. Between these runners debris accumulates fairly rapidly, and as it is not blown away during the winter it contributes to the enrichment of the soil. Many seeds also are retained, and when proper conditions are attained they grow. Some of them may replace the heath altogether. This juniper, as well as the other two heath plants, has seeds which are eaten by birds, although the birds seem to prefer the bright red berries of *Arctostaphylos*. The latter plant, known as the bearberry, is of second importance. What has been said about *Juniperus horizontalis* applies here almost equally well. The development of the runners is not so noticeable, however, and a greater amount of debris is retained in its denser network of branches.

The development of *Juniperus communis depressa* reminds one very strongly of the development of conifers near the tree line in Lapland (Kihlman, 1890). The truncated top of this plant is characteristic of all the individuals wherever they are growing. Some of these tables are a little over a meter in diameter. They vary in hight from about two decimeters up to nearly a meter. The explanation which Kihlman found to solve the problem in Lapland has no bearing in this case, however, for it seldom happens that there is sufficient snow in winter to cover even the lowest of these tables. The explanation lies more probably in the fact that this growth is a germ character of the species, for, in so far as evidence is at hand, edaphic factors merely change the amount of growth and not its manner.

For northern Michigan, where the heath is much better represented than in this region, Whitford (1901:298) lists the character plants as follows: *Juniperus communis, J. horizontalis, Arctostaphylos uva-ursi,* bracken (*Pteris aquilina*), *Zygadenus chloranthus, Solidago nemoralis,* bluebell (*Campanula rotundifolia*), and *Comandra umbellata.* Of the eight species, five occur in the Beach area, and four of these are important members of the heath association.

Secondary species in this association are not very numerous and very few of them are typical of the association. They are either relics of past associations or invaders of succeeding ones. In no case do they add to the general character of the vegetation, although they may greatly change the appearance of individual parts.

The health plants come in on *Calamovilfa* or *Prunus pumila* dunes, which they work over into *Juniperus* dunes. In the meantime the plants spread from the dune over the interdunal spaces. When these

become covered or nearly so, the dune-complex has been changed into a heath. Blowouts occurring in the heath are, in general, revegetated with heath plants rather than with invaders. This will be discussed later, under the general topic of blowouts.

This association is a transitory one of northern affinities, and all the evidence goes to show that it is very gradually being driven entirely from the region. In the northern part of this area it has disappeared already. In the central part north of Dead Lake the *Quercus velutina* association is taking its place. For a little ways south of Dead Lake it is being slowly replaced by pine trees. The only places where the heath is reproducing itself are still farther south, although at the same time the prairie is coming in from the westward more rapidly to take its place.

LIST OF THE SPECIES OF THE HEATH ASSOCIATION

Dominant Species

Juniperus horizontalis
Arctostaphylos uva-ursi
Juniperus communis depressa
Juniperus virginiana (one plant)

Secondary Species

Solidago nemoralis
Petalostemum purpureum f. *arenarium*

Relic Species

Andropogon scoparius
Calamovilfa longifolia
Salix glaucophylla
Koeleria cristata
Salix syrticola
Prunus pumila
Artemisia caudata
Juncus balticus littoralis
Sorghastrum nutans

Invading Species

Ceanothus americanus
Populus deltoides (1.5 m. high)
Quercus velutina
Potentilla fruticosa
Aster ptarmicoides
Panicum virgatum
Populus candicans (0.6 m. high)
Liatris scariosa
Pinus strobus
Pinus laricio
Pinus silvestris
Poa compressa
Hypericum kalmianum
Aster azureus
Tilia americana (one plant 0.5 m. high)

THE PINE FOREST ASSOCIATION

General Location and *History*.—South of the Dead Lake there is approximately a square mile of ground forested by coniferous trees,

forming the pine association. Its present extent is much less than formerly. This is due to cutting, burning, erosion by the lake, and to natural successions. Of the three species of conifers that form the greater part of the association, only one is native to the region. This species, *Pinus strobus,* was formerly relatively common, but is now represented only by a few rather old trees in isolated situations. From the taxonomic nature of the other three species, *Pinus laricio* and *Pinus silvestris* and *Pinus* sp.? it is evident that they have, at some past time, been planted there by man. It has been difficult to secure accurate evidence as to the date, but it was probably sixty or seventy years ago. As long as the groves were taken care of the pines flourished; but with neglect and succession they are slowly disappearing.

Physical and Ecological Characteristics.—The pine association occurs on sandy soil and especially on the ridges of sand. Here, for the first time, there is a definite differentiation between the soil and the subsoil. Where the pines are densest there is a carpet of pine needles, which are gradually being converted into humus. The trees afford plenty of protection for ground plants, but at the same time cut off so much light that ground plants can only occur in the interstices between the trees and in places where a tree has been removed or cut, thus permitting more light to reach the ground. As a result of the ground-covering, water is easily retained and conditions in general are less xerophytic than those on the heath.

The Association.—This association is a representative of the boreal element which has remained as a relic of the postglacial coniferous forests which at one time were dominant in this region. In places where the pines are dense, the association is more typical of its appearance in the northern regions. There are usually few or no secondary species in such situations. The exceptions are false Solomon's seal (*Smilacina stellata*), *Anemone cylindrica,* and *Poa compressa.* The ground is carpeted with needles and pine cones. In places where this association is more open, as along the ridges, there is an abundance of secondary species, all of which represent succeeding associations. Which association does follow, is, of course, determined by the number and nature of the secondary species. In the ridges towards the southward, where the soil is more xerophytic, prairie plants surround the pine trees and often occupy the ground clear up to the trunk of the trees. (Pl. LVI, Fig. 2.) In such places it is impossible for the pine to reproduce itself, as the seeds can not get down to the ground on account of the tangle of prairie grass, debris, etc. As long as the pine trees live, they give the character to the area; when they die, the prairie dominates entirely. Toward the northward, although

there are many prairie species around the trees, there are plenty of young oaks, *Quercus velutina,* in all stages of development. They grow quite easily and are able to replace the pine—not merely to dominate the region with the dying of the pines as is the case with the prairie plants. In the openings in the denser parts of the pine area, the pioneer species that come in are forerunners of both the prairie and the oak forest. Seedling oaks are rather plentiful and occur at various distances from the parent trees, from which acorns were probably carried and stored by birds, especially crows and blue jays. If the oaks are present in any number they determine which succession is to take place.

Pinus strobus occurs rather commonly throughout the association, but it is rather more abundant in the more xerophytic and less fertile soils. It acts as a pioneer for this association, and even now is very gradually reproducing itself on the edges of the prairie and marshes or in broken places in the prairie. This, however, is taking place much more slowly than the occupation of the pine land by oaks. The densest growth of pine is formed largely of *Pinus laricio* and *Pinus silvestris,* growing in separate groves.

LIST OF THE SPECIES OF THE PINE FOREST ASSOCIATION

Dominant Species

Pinus strobus
Pinus laricio
Pinus silvestris
Pinus sp.?
Larix decidua

Secondary Species

Smilacina stellata
Oenothera rhombipetala
Anemone cylindrica
Polygonatum commutatum
Aster azureus

Relic species which are very abundant

Juniperus communis depressa
Juniperus horizontalis
Arctostaphylos uva-ursi
Solidago nemoralis
Euphorbia corollata
Lithospermum gmelini

Relic species which are not abundant

Elymus canadensis
Aster dumosus
Prunus pumila
Salix glaucophylla
Juncus balticus littoralis
Panicum virgatum
Artemisia caudata
Salix syrticola
Arabis lyrata
Sorghastrum nutans
Calamovilfa longifolia
Koeleria cristata

Invading species from the prairie and prairie-like associations

Liatris scariosa
Potentilla fruticosa
Poa compressa
Poa pratensis
Trifolium hybridum
Plantago major
Pycnanthemum virginianum
Taraxacum erythrospermum
Lobelia spicata
Satureja glabra
Zizia aurea
Hypoxis hirsuta
Sisyrinchium sp.?
Phlox pilosa
Castilleja sessiliflora
Tradescantia reflexa
Comandra umbellata
Ceanothus ovatus
Epilobium densum
Equisetum laevigatum

Invading species from the oak forest

Helianthemum majus
Fragaria virginiana
Rubus occidentalis
Verbascum thapsus
Rumex acetosella
Quercus velutina
Salix spp.
Asparagus officinalis
Solidago serotina
Lonicera dioica
Vitis vulpina
Maianthemum canadense
Luzula campestris multiflora
Helianthus occidentalis f. *illinoensis*
Ceanothus americanus
Geranium carolinianum
Lactuca canadensis
Rosa humilis
Pedicularis canadensis

THE QUERCUS VELUTINA ASSOCIATION

As the climax stage of the successions on the ridges of the sand-plain, this forest association exists. The association obtains its start in either of the prairie or coniferous types of vegetation, quite often in broken places in them. It can obtain a slight foothold upon open sand, but more usually the young oaks obtain their foothold in the humus of the prairie or the pines. Development then is quite certain. It is rather more rapid in the prairie situations. As development proceeds the prairie gives way. After a time the ground begins to be more open as the ground-carpet disintegrates to a greater or less extent. Thereupon eremacausis, at least with respect to the upper layers of ground, begins again to be the usual state of affairs. This, coupled with the winds of the more violent storms, causes the surface to reassume a sandy appearance. The sand itself is more or less easily blown, especially where the removal of any of the trees permits a more open exposure. Such blowing results in the formation of what are known as blowouts. While the upper layers may be sandy and the secondary vegetation that of true sand ridges, in which there has

been no intervening prairie stage, the subsoil in which the oaks are rooted is distinctly humic in nature. The secondary species, however, consist of both prairie and sand plants, some of the latter of which, as *Juncus balticus littoralis*, may have persisted through the prairie stage. The same thing happens with respect to the heath. As soon as the oak becomes dominant, by its foliage, light is cut off from the heath plants, and consequently the heath is gradually replaced. With the disappearance of the heath plants the sand is left exposed to blowing. In such situations blowouts are very common. The invasion of the pines takes place much slower because that necessitates the dying of the old pine trees. The oaks can not drive these out as they can the herbaceous vegetation. The young pines can not germinate or develop under the shade of the oaks, which results in the extinction of the pines by the dying of the old trees. As soon as a pine dies, young oaks spring up in its place. They could not do this before on account of the great shade from the pine. Once sufficient light is allowed, the oaks very rapidly replace the spot with trees, against which invasion, in this region, the pines can do nothing.

The *Liatris scariosa* association may develop contemporaneously with the *Quercus velutina*, but usually *Liatris scariosa* develops first, and as it is a fairly open association the *Quercus velutina* quite readily invades it. It retains nearly all of its identity, however, even after invasion, because there is not as yet sufficient food material to support a dense growth of oak. As soon as the oak does become dense, the *Liatris scariosa* gives way.

In its primary stages the *Quercus velutina* association occupies stable sandy soil where humification is the rule. The humus, however, is not abundant, and consequently a luxuriant undergrowth is not developed. Protection against wind and sun is afforded, resulting in a flora somewhat mesophytic in tendency, but the succession of this association to a distinctly mesophytic one requires a space of very many years. In the mature stages of the development of this association humification is very slow and may be absent. The oaks themselves are well developed but their shade keeps out sand plants which would make a dense ground covering, while there is not sufficient food material in the soil to permit the growth of mesophytic forms which require the amount of shade that the oaks furnish. For these reasons eremacausis again takes hold and very materially increases the length of time between this association and the one that will finally succeed it.

Because of its great diversity of environments this association has a large number of secondary species, many of which belong more properly to the associations which the black oak has displaced. The

association is characterized by the black oak, *Quercus velutina,* which is the only dominant species of this association in this region. Other trees are virtually never present. Occasionally a few *Pinus strobus* do remain as relics, and a few trees of *Quercus macrocarpa* and *Q. alba* occupy a mound north of Winthrop Harbor.

The *Quercus velutina* association, as it is found in the Beach region, accords in all essential particulars with Jennings's associations of the same name on Cedar Point, Ohio, and Presque Isle, Pennsylvania (1908 and 1909). The same association occurs throughout Illinois and southern Wisconsin in glaciated land which is xerophytic in nature. In different parts of its range other species of oak also may become dominant, as, for example, *Quercus marilandica* in Mason County, but *Quercus velutina* usually predominates.

LIST OF THE SPECIES OF THE QUERCUS VELUTINA ASSOCIATION

Dominant Species

Quercus velutina

Secondary species which are most characteristic

Achillea millefolium
Amorpha canescens
Anemone cylindrica
Aralia nudicaulis
Arabis lyrata
Asclepias tuberosa
Asparagus officinalis
Aster azureus
Aster sericeus
Baptisia leucantha
Ceanothus americanus
Celastrus scandens
Coreopsis lanceolata
Coreopsis palmata
Desmodium illinoense
Erigeron ramosus
Euphorbia corollata
Fragaria virginiana
Gerardia grandiflora
Gerardia pedicularis
Helianthemum majus
Helianthus divaricatus
Helianthus occidentalis
Lechea leggettii
Lupinus perennis
Lepachys pinnata
Luzula campestris multiflora
Monarda fistulosa
Monarda sp.?
Mosses (unidentified)
Panicum scribnerianum
Pedicularis canadensis
Physalis virginiana
Polygonatum commutatum
Potentilla arguta
Rhus toxicodendron
Rosa humilis
Rudbeckia hirta
Scrophularia leporella
Scutellaria parvula
Silene antirrhina
Silene stellata
Smilacina stellata
Solidago arguta
Solidago serotina
Taraxacum erythrospermum

Helianthus occidentalis f. *illinoensis*
Helianthus strumosus
Heuchera hispida
Lactuca canadensis
Tradescantia reflexa
Maianthemum canadense
Verbascum thapsus
Vitis vulpina
Zizia aurea

Relic species which are most abundant

Arctostaphylos uva-ursi
Juniperus communis depressa
Juniperus horizontalis
Koeleria cristata
Lespedeza capitata
Liatris scariosa
Lithospermum gmelini
Oenothera rhombipetala
Panicum virgatum
Panicum spp.
Poa compressa
Solidago nemoralis

Secondary species which are less characteristic

Antennaria sp.?
Arenaria stricta
Asclepias syriaca
Aster novae-angliae
Carex bebbii
Chenopodium album
Convolvulus sepium
Equisetum arvense
Erigeron canadensis
Hypericum sp.?
Plantago major
Poa pratensis
Polygala sanguinea
Polygala verticillata
Prenanthes alba
Pteris aquilina (rare)
Rosa blanda
Sambucus canadensis
Silphium integrifolium
Sisymbrium officinale leiocarpum
Smilax hispida
Solanum nigrum
Solidago canadensis
Stipa spartea
Trifolium repens
Viburnum lentago

Relic species which are less abundant

Acerates viridiflora
Andropogon furcatus
Andropogon scoparius
Artemisia caudata
Asclepias incarnata
Aster dumosus
Aster ptarmicoides
Betula alba papyrifera
Calamovilfa longifolia
Carex muhlenbergii
Ceanothus ovatus
Comandra umbellata
Eryngium yuccifolium
Lobelia spicata
Oxypolis rigidior
Petalostemum candidum
Petalostemum purpureum
Pinus strobus
Populus deltoides
Populus tremuloides
Prunus serotina
Pycnanthemum virginianum
Rynchospora capillacea leviseta
Salix glaucophylla
Salix longifolia
Salix pedicellaris

Eupatorium purpureum maculatum
Hypericum kalmianum
Juncus balticus littoralis
Liatris spicata
Salix spp.
Scleria triglomerata
Solidago graminifolia
Spiraea salicifolia

Invading species, none of which are abundant

Allium cernuum
Amphicarpa monoica
Aster macrophyllus
Geranium carolinianum
Nepeta cataria
Polygonum persicaria
Prunella vulgaris
Quercus alba (very few)
Quercus macrocarpa (few)
Rudbeckia subtomentosa
Smilax ecirrhata
Sanicula marilandica

In burns:

Apocynum androsaemifolium
Epilobium angustifolium
Helianthus grosseserratus
Populus deltoides
Populus tremuloides

Species whose occurrence is accidental

Apios tuberosa
Catalpa speciosa (planted)
Cirsium arvense
Cyperus rivularis
Krigia amplexicaulis

THE BLOWOUT ASSOCIATIONS

Blowouts are open sandy places evacuated by the wind. They may occur in almost any of the associations that inhabit sandy ground. They are usually started during the winter when the ground is not well protected by vegetation. Once begun, however, any wind with sufficient power to move sand may effect their greater development. As a rule, in this region vegetation is more than able to keep pace with any blowing that may take place, and so there is but little blowout development during the growing season. Blowouts are especially liable to occur in the sand ridges, no matter whether these are tenanted by the heath, the *Liatris scariosa,* or the *Quercus velutina* association. The blowouts of greatest extent occur in the *Quercus velutina* association, more especially where trees have been removed. This is because the shade from the oaks has reduced the density of the vegetation underneath them and left more ground exposed to the wind.

In general, the blowouts are elliptic to oval in shape with their major axis north-northeast or north-northwest. Occasionally a circular blowout may be found and less frequently crescent-shaped ones. Winds from all directions of the compass are responsible for blowouts of greater or less extent, but the largest ones are formed by

either the northwest or the southwest winds, either one of which is quite likely to be strong.

In some regions the flora of even quite widely separated blowouts is remarkably uniform, but this can hardly be said to be true of this region. The blowout is in some measure dependent upon the surrounding associations for most of its species, but there are a few characteristic blowout species which do not occur in associations immediately adjoining the blowout; as, for example, green milkweed (*Acerates viridiflora lanceolata*), flowering spurge (*Euphorbia corollata*), *Cyperus filiculmis macilentus, Sporobolus cryptandrus, Oenothera rhombipetala, Cyperus schweinitzii, Corispermum hyssopifolium,* and horsemint (*Monarda punctata*).Though blowouts occur in several associations, the association that succeeds the blowout need not be the same as the one in which it started. Blowouts occurring in the *Quercus velutina* association sooner or later give place to *Quercus velutina,* often by passing through a heath stage. Blowouts occurring in the heaths may become tenanted by one of several associations: the *Quercus velutina,* a thicket, the *Liatris scariosa,* or the *L. spicata* association. Blowouts in *L. scariosa* may become occupied by *Quercus velutina,* but more frequently by *Liatris spicata*; or, occasionally, by some of the marsh associations, if the blowing should continue during the winter until the bottom of the blowout is below the water-table level. Typical blowouts do not occur in *Liatris spicata,* but occasionally, where the surface-covering of vegetation has been removed by man, blowing ensues. Such blowing does not last long because the sandy bottom is usually damp, and an association such as the *Carex ocderi pumila* soon obtains dominance and finally reverts to *Liatris spicata.* Some of these different types of blowouts are shown in Figure 2, Plate LI, Figure 2, Plate LII, and Figure 1, Plate LIII.

Physically a blowout may be divided into four parts. The low central part, or basin, is occupied by the basin association of deep-rooted perennials, such as *Acerates viridiflora lanceolata.* The windward slope, located on the side from which the sand is being blown, is, with very few exceptions, occupied by the plants of the association in which the blowout occurs. In the prairie blowouts, the windward slope association is characterized by a species of *Panicum, P. huachucae,* a feature which is markedly characteristic of the blowouts at Hanover Station, Jo Daviess County, Illinois (Gleason 1910:79). There, however, a different species, *Panicum pseudopubescens,* is involved. The lee slope, which is directly across from the windward slope, consists of constantly shifting sand, in which the blowsand association of annuals usually dominates. The lee slope usually ter-

minates in a small dunelike ridge, termed the lee deposits, consisting of the sand blown out from the basin. The dunelike form is maintained by sand-binding perennials, many of which are the dune-formers on the lake beach.

Normally very little blowing occurs during the summer, and most of the blowouts show various stages of stabilization. This is most frequently indicated by bush clover (*Lespedeza capitata*), evening primrose (*Oenothera rhombipetala*), and *Panicum virgatum*, although in any single blowout several other species may play the same rôle. With the dying down of the vegetation in the fall, much sand is left exposed to the winter winds, whose blowing power is not usually much hampered by the protection of a snow covering.

LIST OF THE SPECIES OF THE BLOWOUT ASSOCIATIONS

I. Species characteristic of the basin association

Acerates viridiflora lanceolata
Sporobolus cryptandrus
Euphorbia corollata
Lithospermum angustifolium
Lithospermum gmelini
Rhus toxicodendron

II. Other species found in the basin

Cyperus filiculmis macilentus
Oenothera rhombipetala
Koeleria cristata
Carex muhlenbergii
Quercus velutina (seedlings)
Solidago nemoralis
Arctostaphylos uva-ursi
Smilacina stellata
Silene antirrhina
Andropogon scoparius
Scutellaria parvula
Liatris scariosa
Tradescantia reflexa
Juncus balticus littoralis
Rosa humilis
Juniperus horizontalis
Juniperus communis depressa
Opuntia rafinesquii
Amorpha canescens
Juncus torreyi
Rudbeckia hirta
Hypericum kalmianum
Salix glaucophylla
Aster ptarmicoides
Liatris spicata
Eleocharis intermedia
Lobelia kalmii
Potentilla fruticosa
Polytrichum juniperinum
Verbascum thapsus

III. Species characteristic of the windward slope

Panicum huachucae

The other windward slope species are the normal species of the associations in which the blowouts occur, and consequently are not listed.

IV. Species characteristic of the lee slope (blowsand association)

Cyperus filiculmis macilentus
Cyperus schweinitzii
Corispermum hyssopifolium
Monarda punctata
Artemisia caudata
Cenchrus carolinianus
Cakile edentula
Festuca octoflora
Euphorbia polygonifolia
Sporobolus cryptandrus
Cycloloma atriplicifolium

V. Species characteristic of the lee deposits

Panicum virgatum
Oenothera rhombipetala
Lespedeza capitata
*Arctostaphylos uva-ursi**
Tradescantia reflexa
*Juniperus horizontalis**
*Juniperus communis depressa**
Populus deltoides
Asclepias tuberosa
Poa compressa
Prunus pumila
Calamovilfa longifolia
Elymus canadensis
Euphorbia corollata

VI. Miscellaneous species occasionally occurring in blowouts

Chenopodium album
Solidago serotina
Arenaria stricta
Melilotus alba
Hieracium canadense
Aspidium thelypteris
Rynchospora capillacea leviseta
Linum sp.?
Satureja glabra
Aster azureus
Pycnanthemum virginianum
Trifolium repens
Solidago ohioensis
Orobanche fasciculata (parasitic on *Artemisia*)

The Associations of the Marsh Habitats

In the low ground back of the fringing dune and south of Beach are two small bodies of water known as the Dead River and the Little Dead River. The former expands in width as it nears Lake Michigan and becomes what is know as Dead Lake. The small drainage area commanded by these rivers is very level, and consequently there is very little flow of water. For the greater part of the year the outlets into Lake Michigan are closed by a ridge of sand. The surplus water, at these times, is partly evaporated away, partly sinks through the sand to the lake-level, and is partly taken up by the plants which grow along the shores. In general physical charac-

*The asterisk denotes that the species spreads in from surrounding areas by vegetative growth.

teristics these situations are quite similar to lake beaches. The important difference is the slow movement of the water in the rivers, which are not sufficiently extensive to permit the wind to raise waves which could destroy the vegetation along the shores. The bottom of these rivers is seldom more than one or two meters below the level of Lake Michigan.

The associations which occur in these localities are characterized by the great abundance of a very few species. The associations are restricted to narrow bands which spread out horizontally for many meters. This gives rise to zones of associations around the ponds and along the streams. The associations may alternate to a limited extent. They are, however, sharply separated from one another by definite tension lines, which are sharpest between the associations farthest out in the water. Landward the tension lines are occupied by species of both of the bordering associations and in many cases by small plants which occur there only.

THE PLANKTON ASSOCIATION

The free-swimming *protozoans* and algae which enter into the plankton were not investigated, owing to lack of proper facilities for such work.

THE CHARA ASSOCIATION

The bottom of the deeper parts of lakes and ponds in northern Illinois and Indiana is usually covered with an alga, *Chara,* constituting the *Chara* association. There are no secondary species with the *Chara,* as it normally occurs in this area. In streams with visibly running water there is no *Chara.* The accumulation of *Chara* furnishes a lodging place for the seeds of *Potamogeton,* giving rise to the following association.

THE POTAMOGETON ASSOCIATION

This association occurs in both quiet and running water, although usually with different dominant species in the two cases. The association consists mainly of plants that are entirely submerged, although some of them may mature their flowers and fruit at the surface of the water. This association frequently starts near the edge of the *Chara,* or it just as frequently has its beginning in ponds in which there is no *Chara.* In the main part of Dead Lake the association is characterized by a single species, *Potamogeton natans.* In some of the ponds, where the water is not so deep, it may have

associated with it *Myriophyllum verticillatum.* In little streams of running water the dominant species is usually *Potamogeton foliosus niagarensis,* and associated with it are *Myriophyllum verticillatum* and *Elodea canadensis.* In one such little stream *Myriophyllum* and *Elodea* occur almost to the exclusion of the *Potamogeton.* This association is developed to such a limited extent that in a description of this region no adequate idea can be given of it. A more detailed account may be found in Jennings (1909).

THE CASTALIA-NYMPHAEA ASSOCIATION

In shallower water than that occupied by the Potamogetons is the *Castalia-Nymphaea* association. The water is quiet and a layer of mud covers the bottom. The plants of this association are essentially submerged, but they frequently have their leaves at or above the surface of the water. They may mature their flowers and fruits under water, at the surface, or above the water. This association is very effective in accumulating matter which builds up the bottom. This work is furthered not only by the petioles of the water-lilies, which serve to catch materials, but also by the semi-floating secondary species when they occur. The large leaves of the water-lilies, spreading out on the surface, serve to keep the water calm, and this permits a deposition of the matter brought there in suspension. The very noticeable accumulation of organic matter on the bottom is correlated with slow subaqueous oxidation.

The Association.—This association is not well represented in the area. In only one pond do both the species which give the name to the association occur. When this happens, the white water-lily (*Castalia tuberosa*) appears to prefer deeper water than the yellow water-lily (*Nymphaea advena*). *Castalia* is not usually emersed, while *Nymphaea* frequently grows above the water. In this particular pond, associated with the water-lilies are *Ceratophyllum demersum, Chara, Potamogeton* sp.?, and *Elodea canadensis.* In all the other places in this region where this association occurs, it is represented by the dominant species, *Nymphaea advena,* and there are seldom any secondary species with it. (See Pl. LIII, Fig. 2.) Not only does *Nymphaea* occur along the ponds in the swales, but it also grows in a good many of the ditches and holes that have been dug in the right of way of the Chicago and North Western railway. Only one case is at hand to give an idea of how long it takes for the *Nymphaea* to appear in a ditch after it has been dug. In an excavation made during the summer of 1906 *Nymphaea* appeared in

the permanently standing water during the season of 1909. Its nearest possible source was about forty meters away, and the probable agent in dispersal was a marsh bird. Occurring with *Nymphaea* in some of these artificial situations, as well as in natural ones, were *Polygonum amphibium hartwrightii* and *Sparganium eurycarpum,* which more properly belong to other associations. In areas in the western part of Lake County, Illinois, this association is often dominated during the fall by the tall stems of *Pontederia cordata,* but until three examples of it were found during the summer of 1910, this plant was what Harper (1906:329) has termed a "notable absentee."

LIST OF THE SPECIES OF THE CASTALIA-NYMPHAEA ASSOCIATION

Dominant Species

Castalia tuberosa — *Nymphaea advena*

Secondary Species

Pontederia cordata — *Potamogeton* spp.
Ceratophyllum demersum — *Elodea canadensis*
Potamogeton natans

Relic Species

Chara sp.

Species of accidental occurrence

Polygonum amphibium hartwrightii — *Sparganium eurycarpum*

THE RANUNCULUS AQUATILIS CAPILLACEUS ASSOCIATION

After the establishment of the *Nymphaea* association around the margin of many of these ditch pools, plants of *Ranunculus aquatilis capillaceus* appear at the lower (inner) edge of the *Nymphaea.* Thence they spread out, and in time usually cover the surface of the open water. The vegetation floats out towards the center of the water, while the roots remain in the *Nymphaea.* The mass of *Ranunculus* becomes so dense in some of the smaller pools that it can support the weight of marsh birds. The flowers of this plant are borne two or three centimeters above the water on slender hollow stems. While the plant is in bloom the pool appears almost white. With the *R. aquatilis capillaceus* are occasionally a few plants of *R. delphinifolius,* and mixed in with the leaves are colonies of *Lemna minor.* This association is one of the many small associations of water-plants which are rather local in their distribution even in a given area. Ultimately it will be displaced by the *Castalia-Nymphaea* association.

THE LEMNA-RICCIA ASSOCIATION

An alternating association with the one just described is the *Lemna-Riccia* association. It shows a tendency to inhabit the longer, narrower pools, where there is less chance of the wind disturbing the water. The plants differ from those of the *Ranunculus* association in that they are free-floating. They mass together, however, in great mats which cover the surface of the water with vegetation. *Lemna* seems to prefer the more open water, while *Riccia* shows a tendency to remain nearer the border association of *Nymphaea* or *Typha*. The *Lemna* and the *Riccia* are, however, so intermingled with one another that they have essentially the same ecological conditions to meet, and so are parts of the same association. This association can only exist as such in quiet water, for in streams the plants are washed away. On this account it is more conspicuous in the small pools, although careful search usually revealed its plants, especially the *Lemna*, among the grasses or sedges that form the bordering amphibious vegetation of the rivers. Numerous small animal forms are associated with these plants, but no other species of plants have been observed with it in this region.

THE MENYANTHES-SAGITTARIA ASSOCIATION

In fairly wide and shallow (2-4 dm.) sloughs the *Castalia-Nymphaea* association occupies the central part, where there is a little running water, especially during the spring floods. Bordering it on either side is the expanse of the *Menyanthes-Sagittaria* association, which reaches to the sedges. As it occurs in a few of the situations it is a typical bog, like those so much more common farther north. The bottom is very level and somewhat peaty. The plants of this association have their root systems entirely submerged, while the leaves and the flowers are usually above the surface of the water. The vegetation is very dense, as shown in the center of Figure 2, Plate LIII.

Arrowleaf (*Sagittaria latifolia*) is always one of the dominant species in the bogs that occur in this region. It occurs along streams of running water as well, and associated with it are many of the same secondary species that accompany it in the typical bog situation. This association is boreal in distribution. Here, near its southern limit, as shown in Transeau's map of the distribution of bog plants (1903:406), it is not typically developed. The species that is most abundant in this association in this region, *Sagittaria latifolia*, is not listed by Transeau as a bog plant because it is not characteristically

of this habitat and its range is much wider than that of bogs. Nevertheless, in all the bogs of this region it is one of the dominant species and occupies from thirty to sixty per cent. of the area of the association. The two species that complete the list of the dominant species are given in Transeau's list of the plants characteristic of bogs across northern North America (1903:405). Of the two, buckbean (*Menyanthes trifoliata*) is the more abundant, and may form as much as fifty per cent. of the vegetation in some of the bogs, while *Potentilla palustris* is relatively infrequent. Secondary species are not common because the *Sagittaria* and the *Menyanthes* so occupy the area that very little interstitial room remains. Those that occur most abundantly are bladderwort (*Utricularia vulgaris americana*), *Polygonum amphibium hartwrightii, Lysimachia thyrsiflora, Acorus calamus,* and *Proserpinaca palustris.* Towards the edge, an invader of the sedge association, *Carex lanuginosa,* may be within the limits of the association. In less typical situations, especially those near the railway, where the drainage has been interfered with, there are mixtures of this association with species of others near by, the result of which is vegetation of the following composition: *Menyanthes trifoliata, Sagittaria latifolia, Utricularia vulgaris americana, Scutellaria galericulata, Hypericum virginicum, Bidens trichosperma tenuiloba, Iris versicolor, Lysimachia thyrsiflora* and *Polygonum muhlenbergii.* In other situations, differing from these, were *Acorus calamus, Alisma plantago-aquatica, Oxypolis rigidior, Asclepias incarnata, Polygonum hydropiperoides,* and *Ludvigia palustris* in addition to the dominant species.

Along some of the ditches in the right of way of the Chicago and North Western railway this association is appearing. In most of them the first member to appear is *Menyanthes.* With it are associated *Utricularia vulgaris americana* and *Proserpinaca palustris.* In one case *Menyanthes* and *Proserpinaca* were giving way to *Spartina* and *Cephalanthus,* which is worthy of mention because the two bushes of buttonbush that occur in this station are the only individuals in this region of a species so characteristic of similar situations in other places. *Sagittaria* will not as a rule come into these ditches until they are larger in size, and not even then unless there is some movement in the water.

Along the little streams that lead from the bluff towards Lake Michigan, the *Menyanthes-Sagittaria* association is usually represented by *Sagittaria* alone. With it may occur a few secondary species, as *Oxypolis rigidior, Cyperus fluviatilis, Alisma plantago-aquatica, Proserpinaca palustris, Veronica anagallis-aquatica, Ranunculus delphinifolius, Scirpus atrovirens* and *Penthorum sedoides.*

The dense growth of this association aids very materially in building up the sloughs, after which it is replaced by other associations that would otherwise have been unable to develop.

LIST OF THE SPECIES OF THE MENYANTHES-SAGITTARIA ASSOCIATION

Dominant Species

Menyanthes trifoliata
Sagittaria latifolia
Potentilla palustris

Secondary Species

Utricularia vulgaris americana
Polygonum amphibium hartwrightii
Lysimachia thyrsiflora
Acorus calamus
Proserpinaca palustris
Polygonum muhlenbergii
Scutellaria galericulata
Alisma plantago-aquatica
Oxypolis rigidior
Polygonum hydropiperoides
Ludvigia palustris
Sagittaria heterophylla rigida
Veronica anagallis-aquatica

Relic Species

Nymphaea advena
Ranunculus delphinifolius

Invading species

Carex lanuginosa
Hypericum virginicum
Bidens trichosperma tenuiloba
Iris versicolor
Asclepias incarnata
Scirpus fluviatilis
Scirpus atrovirens
Spartina michauxiana
Cephalanthus occidentalis
Penthorum sedoides

THE CAREX ASSOCIATION

In the bogs, above the *Menyanthes-Sagittaria* association, occurs a sedge association composed almost entirely of species of *Carex*. The sedges grow quite densely, and while above the surface of the water the culms seem to be regularly distributed, beneath the surface they are found to be grouped together in bunches or hummocks. If the water-level is lowered, this gives rise to the hummocks, which are so characteristic of boggy shores. The bottom is decidedly muddy, and the water is shallower than in the two preceding associations. The sedges afford good hiding places for several of the marsh birds and other animals.

There are seldom any secondary species with the sedges. In the bogs, *Utricularia vulgaris americana* and *Iris versicolor* have

been found as secondary species in several stations, and, in addition cardinal-flower (*Lobelia cardinalis*) in a single station. In a few of the ditches along the railway, where this association has found its way, *Spartina michauxiana, Lobelia cardinalis,* and a few plants of *Iris versicolor* take the part of secondary species. *Dulichium arundinaceum,* a typical bog plant, is present in this region in only two very small boggy places in the midst of a succeeding *Populus-Salix-Cornus* thicket, where it was accompanied by *Carex* sp.

Along the shores of Dead Lake, except for a few places where the *Castalia-Nymphaea* association exists, this association of sedges forms the outermost zone of vegetation visible above the water. At the outer edge it is formed solely of two species of *Carex—Carex lanuginosa,* and the other was probably *Carex filiformis,* although none of its flowering culms were obtained. Nearer the shore are invaders of associations occupying shallower water. Among these invaders is *Scirpus validus,* which may, in other lakes, grow in much deeper water than the *Carex* does in the Dead Lake. This leads to the conclusion that, although most of the aquatic and semiaquatic plants are closely restricted within certain depths of water, their position in any given locality is determined by competition of associations rather than by the different physical requirements of the plants. The same relative arrangement is maintained within the limits of the requirements of the individual plants in different localities, even though the absolute conditions may vary greatly.

LIST OF THE SPECIES OF THE CAREX ASSOCIATION

Dominant Species

Carex filiformis
Carex lanuginosa
Carex stricta
Carex comosa
Carex riparia
Carex stipata
Carex buxbaumii
Carex spp.
Dulichium arundinaceum

Secondary Species

Utricularia vulgaris americana
Lobelia cardinalis
Spartina michauxiana
Acorus calamus
Echinochloa crusgalli

Invading Species

Iris versicolor
Scirpus validus
Typha latifolia

THE PHRAGMITES-TYPHA ASSOCIATION

In shallower water than the *Carex* association is the *Phragmites-Typha* association. Ecological conditions seem to be much the same as for the *Carex* except that the water is shallower. The plants of this association are rooted in muddy soil a few decimeters below the water-level and have their vegetative parts comparatively high in the air, where they are exposed to the drying effects of the wind and sun. The cattail (*Typha*) is, in a small measure, adapted to these conditions by having its broad leaves edgewise with the noonday sun. Adaptation would seem hardly necessary since the plants can obtain water as fast as it is evaporated. Even on the hottest and driest days, *Typha* never appears wilted, but *Phragmites* may be quite noticeably wilted. Each of the dominant species dominates the situations in which it is located. Very dense plant families are formed on account of the close method of vegetative reproduction. Although these two species seldom intermingle, they conform exactly to the limits of water-depth in which either will grow. For these reasons, either may be farther out or nearer the shore, or a family of one may be between two families of the other, and this without change of water-depth. There is very little room for secondary species, and the few that do occur are relics or invaders of other associations. When this association appears in the ditches along the railway, the dominant species is usually *Typha* on account of the much greater production of its seeds. In two pools *Typha angustifolia* alternates with *T. latifolia*. Hybrids between these two species occasionally occur, and there is a form having two completely separated spikes of pistillate flowers in addition to the staminate spike.

LIST OF THE SPECIES OF THE PHRAGMITES-TYPHA ASSOCIATION

Dominant Species

Typha latifolia
Typha angustifolia
Phragmites communis

Secondary Species

Acorus calamus (a very little)
Oxypolis rigidior
Utricularia vulgaris americana
Scirpus atrovirens
Scirpus rubrotinctus

Relic Species

Carex lanuginosa (a little)
Proserpinaca palustris

Invading Species

Scirpus validus

The following floating plants are frequently present:

Riccia fluitans *Lemna minor*

THE SCIRPUS VALIDUS ASSOCIATION

In still shallower water than the preceding association occurs the *Scirpus validus* association. It is characterized by the bulrush, *Scirpus validus,* and the very closely related species, *S. heterochaetus* and *S. occidentalis.* The former species grows in water which varies in depth from one to ten decimeters. In this area, and in general in the lake region in northeastern Illinois and southeastern Wisconsin, the *Scirpus validus* association grows in deeper water only when there are no other associations of emersed plants between it and the open water. This association is one of the commonest aquatic pioneers, and will grow either in still water or in a moderate current. Although this association agrees with the *Phragmites-Typha* association and the *Scirpus americanus* association in having the roots in saturated soil and the tops of the plants in the air, they can hardly be grouped into a single association, as Jennings (1909:354) has pointed out, because of the definite arrangement they always exhibit with respect to one another. This differentiation is most evident in the relations of the plants to the varying depths of water. The *Phragmites-Typha* association grows in deeper water than the *Scirpus validus,* while *Scirpus americanus* grows in shallower water and will persist out of the water as a relic. Where *Typha* or *Phragmites* have been found surrounded by *Scirpus validus,* or vice versa, investigation has always shown a difference in level. *Scirpus validus* grows in soil which contains rather more humus than that in which *Typha* grows. Both associations have few secondary species, which for the most part are unimportant. Taken as a whole, the secondary species constitute less than 3 per cent. of the association, the remaining 97 per cent. being the dominant species. Neither *Phragmites* nor *Typha* have more than a very slight ability to persist among *Scirpus validus* as relics, but the *Scirpus* itself is, to a limited extent, capable of being an invader in the *Phragmites-Typha,* and to a greater extent possesses the power of growing as a relic in the *Scirpus americanus* association. The color tone of the *Scripus validus* during the growing season is dark green, which very decidedly separates it from the light green of the *Scirpus americanus.* The two latter associations are shown in Figure 1, Plate LIV, where *Scirpus americanus* occupies the left half and the lower part of the right half of the figure, while *Scirpus validus,* appearing darker in color, is in the upper part of the right half of the figure.

LIST OF THE SPECIES OF THE SCIRPUS VALIDUS ASSOCIATION

Dominant Species

Scirpus validus

Secondary Species

Utricularia vulgaris americana
Acorus calamus (a very little on the lower border)
Spartina michauxiana (dwarfed and but little of it)
Rumex britannica

Relic Species

Nymphaea advena (scarce)
Typha latifolia (only on the lower border and scarce)

Invading Species

Scirpus americanus (on the upper border)

THE SCIRPUS AMERICANUS ASSOCIATION

As has been mentioned, the *Scirpus americanus* association occupies shallower water than the *Scirpus validus* association. The accumulation of humus is greater, and it is sometimes peaty in nature. This association does not occupy ground that is permanently out of water, although sometimes during dry seasons it may be a decimeter or two above the water-level. In such cases, however, the ground is still, as a rule, thoroughly soaked by means of capillary attraction or other agency. If this is not so, the *Scirpus* stems will become dry and brown, but upon restoration of the water to its former level they usually become green again. These light green stems give the characteristic color-tone to the association. When growing in nearly pure damp sand, the *Scirpus* stems are often spirally twisted—a modification exhibited also by *Juncus balticus littoralis,* as mentioned on page 277.

LIST OF THE SPECIES OF THE SCIRPUS AMERICANUS ASSOCIATION

Dominant Species

Scirpus americanus

Secondary Species

Triglochin maritima
Salix candida
Bidens trichosperma tenuiloba
Eleocharis acuminata
Eriophorum angustifolium
Rynchospora capillacea leviseta

Relic Species

Alisma plantago-aquatica
Scirpus validus (scarce)

Invading Species

Solidago graminifolia
Iris versicolor
Aspidium thelypteris
Steironema quadriflorum
Lythrum alatum
Juncus canadensis
Hypericum virginicum
Salix longifolia
Asclepias incarnata

This association is the last of the strictly aquatic associations, whose dominant species compose from 85 to 100 per cent. of their area. The following are land associations in which the dominant species are usually more numerous and more openly distributed in the area. Secondary species are much more numerous, and lead in determining the different seasonal aspects of the associations. The marsh group of associations is transitional to either prairie or forest.

THE CLADIUM MARISCOIDES ASSOCIATION

Developing on mucky soil just back of the *Scirpus americanus,* a little above the hight of standing water but not sufficiently high for the surface to become dry, is the *Cladium* association, about 98 per cent. of whose plants are the sedge, *Cladium mariscoides.* In the youngest swales the *Cladium* and *Scirpus americanus* are adjacent, while in the middle-aged swales they are often separated by the development of the *Calamagrostis canadensis* association on the tension line between them. In the oldest swales the *Cladium* is entirely absent. There is seldom any mingling of these associations, even on their border lines. The vegetation is so dense in the main part of this association that secondary species can obtain a foothold only on the tension line between this and other associations. In level places this association will spread out to a width of 15 or 20 meters, with a uniform structure throughout. More usually, however, it occurs as a zone around ponds or as a belt along swales, seldom attaining a width of one meter, but exhibiting the same uniformity of vegetational structure. During the growing season the color tone of this association is dark green—the color of the stems and leaves. About the first of August the plants come into bloom and the color tone is changed to brown, which makes the association stand out very sharply from the surrounding ones. This is especially the case during years of drought, as 1908 and 1910, when every plant of *Cladium* blooms. During normal seasons, as 1909, when Figure 2, Plate LIV, was taken, scarcely half of the plants bloom. Usually *Cladium* persists from season to season by the growth of the root stalks. The

abundant production of seeds in a dry season is a xerophytic adaptation.

The *Cladium* association may be displaced by a thicket, but in nearly every case it is succeeded by the blazing star (*Liatris spicata*) prairie. This latter succession takes place more easily when the *Cladium* is not restricted to a narrow belt. The species that invades first are usually *Lythrum alatum, Solidago graminifolia, Pycnanthemum virginianum, Oxypolis rigidior, Gerardia paupercula, Epilobium densum,* and *Liatris spicata.*

LIST OF THE SPECIES OF THE CLADIUM MARISCOIDES ASSOCIATION

Dominant Species

Cladium mariscoides

Secondary Species

Hypericum virginianum (scarce) *Spartina michauxiana* (scarce)

Relic Species

Eriophorum angustifolium
Scirpus americanus
Utricularia cornuta
Aspidium thelypteris

Invading species, nowhere abundant in this association

Lythrum alatum
Solidago graminifolia
Pycnanthemum virginianum
Oxypolis rigidior
Gerardia paupercula
Epilobium densum
Potentilla fruticosa
Solidago ohioensis
Eupatorium perfoliatum
Steironema quadriflorum
Liatris spicata
Lycopus americanus
Lycopus sp.?
Osmunda regalis
Iris versicolor (uncommon)
Habenaria psycodes (two individuals)

THE CALAMAGROSTIS CANADENSIS ASSOCIATION

When swales have reached a sufficiently advanced stage of development, *Calamagrostis canadensis* appears on the tension line between the *Cladium* and *Scirpus americanus* associations and ultimately entirely replaces the *Cladium.* The *Calamagrostis* association occupies somewhat mucky soil in which, a little above standing water but not sufficiently high for the surface to become dry, an abundance of *Marchantia polymorpha* may occasionally be found. It is not usually subject to inundation. From 98 to 99 per cent. of the area of this association is occupied by the marsh grass, *Calama-*

grostis canadensis, whose stems grow so closely as virtually to prohibit the development of secondary species. The association varies in width from a meter or two where the slope is evident to thirty to fifty meters or more where there is no evident slope. In all cases the dense growth of *Calamagrostis* completely dominates, and the small number of secondary species, which are usually either relics or invaders, are notably more slender, broader-leaved, and taller than individuals of the same species in their normal associations. This is clearly a response to the diminution of the amount of light which they receive, as this effect is often observed where these plants persist under the shade of trees. The foreground of Figure 1, Plate LV, shows a typically developed *Calamagrostis* swale.

When this association obtains dominance successions are very nearly at a standstill, since the seedlings of invaders have considerable difficulty in obtaining a foothold, and they must also be able to withstand a great deal of shade. Normally the *Liatris spicata* prairie is the association which should succeed. Near Zion City, however, where the swales are occasionally burned over, the thicket association obtains a foothold and is rapidly followed by aspens and willows.

LIST OF THE SPECIES OF THE CALAMAGROSTIS CANADENSIS ASSOCIATION

Dominant Species

Calamagrostis canadensis

(All of the following species are very poorly represented in number of individuals)

Secondary Species

Spartina michauxiana
Campanula aparinoides
Aster ericoides

Relic Species

Scirpus validus
Scirpus americanus
Oxypolis rigidior
Asclepias incarnata
Polygonum amphibium hartwrightii
Dulichium arundinaceum (very rare)

Invading Species

Lythrum alatum
Spiraea salicifolia
Salix candida
Salix longifolia
Iris versicolor
Mentha arvensis canadensis
Eupatorium perfoliatum

THE IRIS VERSICOLOR ASSOCIATION

With the draining of the stations of *Carex* by the lowering of the water-level, or otherwise, the hummocks are exposed. This is usually followed by a marked increase in the number of plants of *Iris versicolor* and a reduction in the amount of *Carex*. Grasses, especially *Poa compressa* and *Poa pratensis,* spread over the hummocks, while *Iris* and the secondary plants for the most part occupy the spaces between the hummocks.

Most of the stations of this association are in the stage characterized above. A few in more advanced stages indicate that if the water-table is further lowered, the *Iris* association will ultimately be replaced either by grass or by the *Liatris spicata* prairie association. In other situations, especially near the foot of the bluff south of Beach, where the ground is more boggy, the *Iris* occupies a tension zone between the carices and the thickets, persisting as a relic in case of succession by the latter association. It is very frequently present as a transition zone between the swale associations and the ridge associations, between which there are usually no successions although they may grow in direct contact with one another.

The association is characterized by plants that prefer a somewhat boggy soil which is always moist yet rarely inundated. The vegetation is very compact and invasion into it is rather slow. This association presents conspicuous aspects during the different seasons. The blooming of the dominant species itself characterizes the spring aspect. During the summer the abundant yellow flowers of *Steironema quadriflorum* again make this association conspicuous. Vervain (*Verbena hastata*), smartweed (*Polygonum punctatum*), *Solidago graminifolia,* and boneset (*Eupatorium perfoliatum*) combine to produce the serotional aspect, while several species, most important of which are ladies' tresses (*Spiranthes cernua*), closed gentian (*Gentiana andrewsii*), *Gerardia paupercula, Gerardia tenuifolia,* and a few asters, make up the fall aspect. Very small, single-flowered plants of *Gentiana procera* continue blooming late in the fall, until finally killed by the severe frosts towards the end of October.

LIST OF THE SPECIES OF THE IRIS VERSICOLOR ASSOCIATION

Dominant Species

Iris versicolor	*Eleocharis intermedia*

Secondary species which are most abundant

Lycopus americanus	*Verbena hastata*
Steironema quadriflorum	*Prunella vulgaris*

Eupatorium perfoliatum
Epilobium densum
Solidago graminifolia
Spiranthes cernua
Gentiana procera
Aspidium thelypteris
Lobelia siphilitica
Gerardia paupercula
Aster paniculatus
Aster salicifolius
Aster spp.
Carex hystericina
Lobelia kalmii
Parnassia caroliniana
Habenaria dilatata
Habenaria hyperborea

Secondary species which are not abundant

Lycopus sp.
Hypericum virginicum
Comandra umbellata
Gentiana andrewsii
Chelone glabra
Polygonum acre
Gerardia skinneriana
Gerardia tenuifolia
Satureja glabra
Cyperus rivularis
Penthorum sedoides
Isanthus brachiatus
Aster spp.
Leersia oryzoides
Rumex crispus
Juncus canadensis
Cicuta bulbifera
Cicuta maculata
Aster novae-angliae
Ranunculus pennsylvanicus
Eupatorium purpureum maculatum
Apocynum cannabinum hypericifolium
Cirsium muticum
Habenaria clavellata
Habenaria leucophaea
Osmunda regalis
Tofieldia glutinosa
Polygala sanguinea
Drosera rotundifolia
Galium boreale
Pogonia ophioglossoides
Symplocarpus foetidus
Cypripedium hirsutum
Pedicularis lanceolata

Relic Species

Calamagrostis canadensis (few)
Spartina michauxiana
Alisma plantago-aquatica
Potentilla palustris
Lysimachia thyrsiflora

Invading Species

Rudbeckia hirta
Pycnanthemum virginianum
Lythrum alatum
Galium trifidum
Salix candida
Spiraea salicifolia
Betula pumila

THE OSMUNDA ASSOCIATION

A few patches of *Osmunda regalis* which occur on the border of the *Calamagrostis* association are all that remain to indicate a big as-

sociation which has been driven from the region. Usually the *Osmunda* is between the *Calamagrostis* and the prairie, but it is also between the *Quercus velutina* and the *Calamagrostis,* and less frequently is preserved as a relic in the midst of willow thickets which have been developed in boggy ground. *Osmunda cinnamomea* is a very characteristic species of this association, but it is entirely absent from the Beach region. The only associates that have been noted with the *Osmunda regalis* are *Geranium maculatum, Fragaria virginiana, Polytrichum* sp., and *Zizia aurea.*

THE POTENTILLA FRUTICOSA ASSOCIATION

This northern association occurs on sandy soil which is usually moist, although only exceptionally flooded. The association typically follows the destruction of the pines in a soil which can support an association genetically higher than bunch-grass prairie, but not yet sufficiently mesophytic for the blazing star (*Liatris spicata*) prairie. It often occupies the lower ground between the ridges on which the pines are growing.

The Association.—The wide-spread growth of the dominant species, *Potentilla fruticosa,* a low bushy plant, is the characteristic feature of the association. Few or no characteristic secondary species occur, since this association is a boreal relic. Other species that may occur are usually relics or invaders of former or succeeding associations. The composition of the invaders depends almost entirely upon the proximity of the associations likely to succeed. In the southern part of the region, especially towards Waukegan, this association is so intermingled with the *Liatris spicata* prairie that it is difficult to separate them. Throughout most of the year this association presents a dull, monotonous color-tone, but in the late summer it is relieved by the bright yellow flowers of the *Potentilla,* which occur in profusion.

Successional Relationships.—Shrubby cinquefoil (*Potentilla fruticosa*) has more ability to invade and take possession of bunch-grass prairie than *Liatris spicata* prairie, but in turn the *Potentilla* is almost immediately followed by *Liatris spicata.* Near the pines *Potentilla fruticosa* easily invades the heath and prepares it for subsequent prairie invasion. *Potentilla fruticosa* readily takes possession of the moister places where pines have been removed, while the heath is characteristic of the drier places. Seedling pines (*Pinus strobus*) occasionally obtain a foothold in the *Potentilla fruticosa,* while seedling oaks (*Quercus velutina*) are less liable to do so. In general, however, oaks will obtain dominance quicker in cut-over pine land

which is not subsequently occupied by *Potentilla fruticosa*. In other words, ground that is covered with a good stand of *Potentilla fruticosa* is more easily invaded by prairie than by oak.

LIST OF THE SPECIES OF THE POTENTILLA FRUTICOSA ASSOCIATION

Dominant Species

Potentilla fruticosa
Hypericum kalmianum

Secondary Species

Senecio balsamitae
Habenaria dilatata
Habenaria hyperborea
Sisyrinchium sp.
Solidago graminifolia
Cladonia spp.
Mosses

Relic Species

Euphorbia corollata
Rudbeckia hirta
Smilacina stellata
Anemone cylindrica
Lithospermum gmelini
Solidago nemoralis
Pinus strobus (by cutting)
Arabis lyrata
Potentilla anserina
Elymus canadensis
Artemisia caudata
Juniperus horizontalis
Arctostaphylos uva-ursi
Arenaria stricta
Ceanothus americanus
Calamovilfa longifolia
Tradescantia reflexa
Pteris aquilina
Osmunda regalis

Invading Species

Pycnanthemum virginianum
Krigia amplexicaulis
Liatris spicata
Pinus strobus (few)
Erigeron ramosus
Petalostemum candidum
Lobelia spicata
Prunella vulgaris
Spiraea salicifolia
Fragaria virginiana
Poa compressa
Salix spp.
Bromus kalmii

THE LIATRIS SPICATA PRAIRIE ASSOCIATION

Spread over the low ridges of the southern part of the Beach area occurs the best development of the southwestern or prairie element of the flora of this region. In the forested parts of the region the prairie associations occupy belts or zones between the swale assocations and those of the forest. The area between the Dead Lake and the Chicago and North Western railway, which was

formerly dominated by swamp associations, is now very largely being replaced by the prairie association, which in turn is slowly giving way to the oak forest.

Physical and Ecological Characteristics.—The area covered by the prairie has an ample precipitation, distributed quite equally throughout the year. In addition the ground is but very little elevated above the surface of Lake Michigan. According to Schimper (1903) this ought to mean that the ground is forest-covered. At the present time this is not the case, but all indications look toward that succession ultimately. In former years, at which time the lake level was higher, this region was swampy and was occupied by swamp associations, relics of which are easily found in the prairie at the present time. The swamp associations formed a layer of black soil on the sand, upon which the prairie plants spread quite rapidly as soon as they obtained a foothold. Lowering of the Lake Michigan level has led to a partial draining of much of this land. Many of the swamp plants can still live under the new conditions, with prairie species, but they are gradually being displaced. As the land is drained, more and more prairie plants have the ability to effect ecesis even in the dense growths of swamp plants. Under normal conditions oaks do not possess this ability. They can reproduce under such conditions if the acorns are actually planted, but in the dense coating of vegetation in swamps and prairies this rarely happens except accidentally. This explains why prairies rather than forests came to occupy the swamp areas.

The Association.—This prairie association is made up of herbaceous plants, nearly all of which die down to the ground each year. The association is characterized by the great abundance of individuals of a few typical species together with scattering plants of many secondary species. The season is separated into several well-marked aspects by the changes due to the blooming of the different important species. The vernal aspect is characterized by phlox (*Phlox pilosa*), painted cup (*Castilleja coccinea*), shooting star (*Dodecatheon meadia*) and lobelia (*Lobelia spicata*). *Phlox glaberrima* is dominant in the estival aspect. (See Fig. 2, Pl. LV.) Between the estival and the serotinal aspects occurs the blooming of *Calopogon pulchellus* and *Lilium philadelphicum andinum*, which for a short time produces another aspect. The serotinal aspect results from the great abundance of blazing star (*Liatris spicata*), as shown in Figure 1, Plate LVI, and by a lesser abundance of *Pycnanthemum virginicum*, *Lythrum alatum*, *Petalostemum purpureum*, and *Eryngium yuccifolium*. During the fall the blooming of goldenrods and asters,

but particularly *Solidago ohioensis,* characterizes the association. The dead standing stems of many of these plants remain over winter.

Successional Relationships.—This association is preeminently an association inhabiting low ridges which have a coating of black soil. Accordingly it is usually able to succeed any association which forms black soil. This is especially true in the case of the genetically highest swamp associations, which, in spite of their density, the *Liatris spicata* prairie is able to invade and replace as long as the water-content factor of the soil is not prohibitive to its development. In the more sandy swales between the ridges of pine near the lake, shrubby plants of *Potentilla fruticosa* frequently obtain dominance, with nearly the same set of secondary species. *Liatris spicata* is rather scarce at present in such areas, but shows every indication of ultimately replacing them with prairie. As has been shown before, a dense prairie sod prevents the invasion of oaks, but wherever it may be broken, or near its margins, oaks can obtain a foothold. It can readily be seen, therefore, that under the present climatic conditions the final outcome of the prairie areas of this region is, or will be, an oak forest.

LIST OF THE SPECIES OF THE LIATRIS SPICATA PRAIRIE ASSOCIATION

Dominant Species

Liatris spicata
Phlox pilosa
Phlox glaberrima
Castilleja coccinea
Dodecatheon meadia
Lilium philadelphicum andinum
Pycnanthemum virginianum
Lythrum alatum
Solidago ohioensis
Solidago riddellii
Rudbeckia hirta
Senecio balsamitae
Sorghastrum nutans
Andropogon furcatus
Allium cernuum
Petalostemum purpureum

Secondary Species

Aletris farinosa
Apocynum cannabinum hypericifolium
Aster novae-angliae
Aster ptarmicoides
Aster spp.
Calopogon pulchellus
Erigeron ramosus
Erigeron philadelphicum
Eryngium yuccifolium
Anemone virginiana
Aster dumosus
Astragalus canadensis
Bromus kalmii
Comandra umbellata
Desmodium illinoense
Coreopsis lanceolata villosa
Coreopsis palmata
Eupatorium perfoliatum (abundant)

Euphorbia corollata (abundant)
Fragaria virginiana
Helenium autumnale
Heuchera hispida
Hierochloe odorata
Hypoxis hirsuta
Lactuca canadensis
Lespedeza capitata
Liatris cylindracea
Lobelia siphilitica
Lobelia spicata
Poa compressa
Poa pratensis
Potentilla arguta
Rumex crispus
Sisyrinchium sp.
Solidago graminifolia
Solidago serotina
Solidago speciosa
Solidago speciosa angustata
Vicia americana
Valeriana edulis
Zizia aurea
Eupatorium purpureum
. maculatum
Glyceria nervata
Helianthus grosseserratus
Helianthus occidentalis
Helianthus maximiliani
Krigia amplexicaulis
Lathyrus palustris myrtifolius
Lepachys pinnata
Lilium canadense
Pedicularis lanceolata
Petalostemum candidum
Polygala polygama
Polygala verticillata
Prenanthes racemosa
Satureja glabra
Silphium integrifolium
Silphium terebinthinaceum
Tofieldia glutinosa
Tradescantia reflexa
Vernonia fasciculata
Viola papilionacea
Viola sagittata
Scleria verticillata

Relic species in normal genetic succession

Acerates viridiflora
Amorpha canescens
Arabis lyrata
Arctostaphylos uva-ursi
Juniperus communis depressa
Juniperus horizontalis
Aspidium thelypteris
Aster azureus
Calamovilfa longifolia (rarely)
Elymus canadensis
Euphorbia corollata
Gerardia tenuifolia
Gerardia paupercula
Gerardia skinneriana
Hypericum kalmianum
Koeleria cristata
Betula alba papyrifera
Achillea millefolium
Andropogon scoparius
Arenaria stricta
Artemisia caudata
Asclepias incarnata
Asclepias purpurascens
Asclepias syriaca
Asclepias tuberosa
Carex oederi pumila
Carex spp.
Eupatorium perfoliatum
Habenaria clavellata
Habenaria dilatata
Habenaria leucophaea (3 plants)
Iris versicolor
*Liatris scariosa**
Campanula aparinoides

Betula pumila
Juncus balticus littoralis
Juncus canadensis
*Juncus torreyi**
Osmunda regalis
Oxypolis rigidior
Parnassia caroliniana
Polygonum hydropiperoides
Potentilla anserina
Potentilla fruticosa
Rynchospora capillacea leviseta
Scirpus americanus
Scirpus atrovirens
Scirpus lineatus
Solidago nemoralis (scarce)
Steironema quadriflorum
Linum virginianum
Lithospermum gmelini (scarce)
Lobelia cardinalis
Lycopus americanus
Panicum virgatum
Pinus strobus
Pinus laricio
Pinus silvestris
Rhus toxicodendron
Salix candida
Salix glaucophylla
Salix syrticola
Scleria triglomerata
Spartina michauxiana
Alisma plantago-aquatica

Relic species remaining after the removal of oak groves

Anemone cylindrica
Heracleum lanatum
Pedicularis canadensis
Prunella vulgaris
Smilacina stellata
Ceanothus americanus
Monarda mollis
Podophyllum peltatum
Pteris aquilina
Smilax ecirrhata

Invading species of the thicket associations

Cirsium muticum
Populus deltoides
Populus tremuloides
Sambucus canadensis
Spiraea salicifolia
Salix spp.
Cornus stolonifera
Rhus hirta
Salix cordata
Salix discolor
Salix pedicellaris

Invading species of the woods

Quercus velutina
Carya ovata (a few seedlings)
Vitis vulpina
Sanicula marilandica
Geum canadense
Agrimonia gryposepala

Species of accidental occurrence

Ambrosia artemisiaefolia
Convolvulus sepium
Trifolium repens
Bromus tectorum
Salsola kali tenuifolia

*The two species marked with an asterisk also play the rôle of invaders where the water-table is being lowered beyond the requirements of the *Liatris spicata* prairie.

THE JUNCUS TORREYI ASSOCIATION

This small association, composed virtually of only the dominant species, occupies very definitely the tension line between the blazing star (*Liatris spicata*) and the *Liatris scariosa* associations. It may extend slightly into both of them, but in such cases is evidently acting as an invader in one and a relic in the other. This depends upon which *Liatris* association is succeeding the other, since that succession is reversible and bears a seemingly definite relation to elevation or depression of the water-table. The large dark green to brown heads of the dominant species make this association stand out very distinctly from each of its neighbors. The usual width of the association is five to twenty-five centimeters, though it may be greater or less according to the slope of the land. In blowouts where neither *Liatris* is present, this *Juncus* occupies very definitely the median position between the sets of plants which represent those two associations.

LIST OF THE SPECIES OF THE JUNCUS TORREYI ASSOCIATION

Dominant Species

Juncus torreyi

Relic or Invading Species (depending on the direction of succession)

Rynchospora capillacea laeviscta *Steironema quadriflorum*

THE THICKET ASSOCIATIONS

THE POPULUS-SALIX-CORNUS THICKET ASSOCIATION

This association is one of the usual steps in the succession from marsh to oak forest. It is quite general in its distribution throughout the central part of the Beach area. It may invade almost any association, but it is most successful in the *Liatris spicata, Calamagrostis canadensis, Iris versicolor,* and blowout associations.

Physical and Ecological Characteristics.—This association grows in soil varying from sandy loam to the black soil of the prairie. The water supply is always ample on account of the proximity of the water-table level of Lake Michigan. The growth of the thickets is very dense, and in the protection thus afforded considerable humus may be formed.

The Association.—The association is composed of any one of the dominant species or of different combinations of them. Dogwood (*Cornus stolonifera*) and the species of willow (*Salix*) are each much more abundant than the species of *Populus.* There seems to

be no particular arrangement of the dominant species when they occur together, except in the more pronounced ridges. Here *Populus* occupies the crest and *Salix* and *Cornus* the slopes. With them are a number of secondary species, many of which are either invaders of the forest type of vegetation or relics of the prairie.

Successional Relationships.—On sandy ground this association is very frequently introduced by the invasion of cottonwood (*Populus deltoides*), followed by species of *Salix* and *Cornus*. In black soil, species of *Salix* or *Cornus* are more usually the pioneer invaders. Succession is accomplished by the cutting-off of the light supply from the vegetation below as soon as the shrubs attain sufficient size. In due course of time some of the species of *Salix* and *Populus* become trees, with almost the same assemblage of secondary species, but ultimately the thickets occurring on the beach plain will be replaced by the *Quercus velutina* association, while those near the base of the bluffs will be replaced by the oak-hickory woods.

LIST OF THE SPECIES OF THE POPULUS-SALIX-CORNUS THICKET ASSOCIATION

Dominant Species

Cornus stolonifera
Populus tremuloides
Populus deltoides
Rosa carolina
Salix amygdaloides
Salix cordata
Salix discolor
Salix longifolia
Salix lucida
Salix pedicillaris
Salix serissima

Secondary Species

Aster umbellatus
Aster novae-angliae
Betula alba papyrifera
Betula pumila
Bromus incanus (1 plant)
Dioscorea paniculata
Equisetum arvense
Helianthus occidentalis f. *illinoensis*
Helianthus grosseserratus
Lactuca canadensis
Lechea leggettii
Lechea villosa
Lonicera dioica
Prunus serotina
Ribes sp.?
Rhus toxicodendron
Rhamnus alnifolia
Rubus occidentalis
Spiraea salicifolia
Solidago canadensis
Solidago serotina
Sambucus canadensis
Silphium integrifolium

Relic Species

Achillea millefolium
Lespedeza capitata

Agrostis alba
Amorpha canescens
Andropogon furcatus
Asclepias incarnata
Asclepias syriaca
Asclepias tuberosa
Aspidium thelypteris
Aster azureus
Aster dumosus
Betula alba papyrifera
Betula pumila
Calopogon pulchellus
Desmodium illinoense
Erigeron ramosus
Eupatorium purpureum maculatum
Euphorbia corollata
Habenaria psycodes
Juncus balticus littoralis
Koeleria cristata
Krigia amplexicaulis
Lathyrus palustris myrtifolius
Liatris spicata
Lobelia spicata
Lythrum alatum
Oxypolis rigidior
Panicum virgatum
Parnassia caroliniana
Pedicularis lanceolata
Petalostemum candidum
Potentilla fruticosa
Prenanthes racemosa
Prunus pumila
Pycnanthemum virginianum
Rynchospora capillacea leviseta
Rudbeckia hirta
Salix glaucophylla
Salix syrticola
Silene antirrhina
Solidago ohioensis
Solidago graminifolia
Sorghastrum nutans
Tradescantia reflexa
Zizia aurea

Invading Species

Acer negundo
Acer saccharinum
Aralia nudicaulis
Echinocystis lobata
Geranium maculatum
Maianthemum canadense
Carya ovata
Monarda fistulosa
Polygonatum commutatum
Quercus velutina
Smilacina stellata
Smilax hispida
Vitis vulpina
Juglans nigra

THE PRUNUS THICKET ASSOCIATION

While over 90 per cent. of the thickets of this region belong to the *Populus-Salix-Cornus* thicket association, there are, along the north bank of the Dead Lake, a few thickets which belong to a different association. Their position and composition are about the same as the sand river-bank thickets occurring along the Mississippi River in the vicinity of Hanover, Illinois, described by Gleason (1910:142). The bushes form the dominant part, but mixed in with them are lianas, which in places make the vegetation difficult to penetrate. The ground is sandy at the surface, although below it may be somewhat

loamy. These thickets grow in and around the borders of the pines, effectually cutting off their chances of reproduction. The central parts of the thickets are too dense for the ecesis of oaks, but towards the edge, where it is more open, black oak, *Quercus velutina,* quite readily obtains a foothold and in time replaces the thicket.

The marked differences between these two kinds of thickets are the possession of lianas and the sandy-appearing soil in the *Prunus* thickets, while the *Populus-Salix-Cornus* thicket, with virtually no exceptions, is free from lianas and has somewhat loamy or mucky soil.

LIST OF THE SPECIES OF THE PRUNUS THICKET ASSOCIATION

Dominant Species

Prunus pumila
Prunus serotina
Prunus virginiana
Sambucus canadensis

Secondary Species

Lianas:

Vitis vulpina
Celastrus scandens
Rhus toxicodendron radicans

Herbaceous plants:

Anemone canadensis
Asparagus officinalis
Aster spp.
Fragaria virginiana
Lathyrus venosus
Veronica virginica
Melilotus alba
Rosa humilis

Relic Species

Calamovilfa longifolia
Euphorbia corollata
Oenothera rhombipetala
Phlox pilosa
Poa compressa
Potentilla fruticosa
Solidago nemoralis
Artemisia caudata (few)
Juncus balticus littoralis
Koeleria cristata
Petalostemum purpureum
Salix glaucophylla
Polygonatum biflorum (where oaks have been cut)

Invading Species

Quercus velutina

Up to the present point, the discussion of associations has been limited to those of the sand-plain. The bluffs which constitute its western boundary are tenanted by arboreal associations which show an inclination to invade the prairie, although, up to the present

time, very little has been accomplished. The most widely distributed is the oak-hickory association, in which the following species are the most important: bur oak (*Quercus macrocarpa*), red oak (*Quercus rubra*), white oak (*Quercus alba*), shell-bark hickory (*Carya ovata*), *Carya cordiformis,* and *Juglans nigra,* together with many secondary species. It is an association of essentially loamy or clayey soil, and does not readily invade the sandy areas. On moister ground occurs a more mesophytic association of trees, the *Ulmus-Acer* association, whose characteristic species are elm (*Ulmus americana*), soft maple (*Acer saccharinum*), basswood (*Tilia americana*), and white ash (*Fraxinus americana*). This in turn is succeeded by the climax association of this region, the sugar maple (*Acer saccharum*) association, which at the present time is in the infancy of its development in northeastern Illinois.

The following cross-sections, or transects, taken in the southern part of the region, will aid in the understanding of the region. The sections were obtained by listing the changes in the associations, while walking across the area from east to west.

SECTION OF THE ASSOCIATIONS OF THE BEACH AREA MADE ALONG THE LINE OF THE WAUKEGAN SEWER, AUGUST, 1909

1. Lake Michigan.
2. Open sand of lower beach.
3. Beach pool with *Chlamydomonas* and *Oscillatoria.*
4. Open sand.
5. *Cakile-Xanthium* association on the middle beach.
6. *Salix syrticola* dune.
7. *Potentilla anserina* association.
8. *Salix syrticola* dune with a little *Calamovilfa.*
9. *Andropogon scoparius* bunch-grass prairie.
10. *Populus-Salix* dune, 0.1 to 0.4 meter high.
11. *Calamovilfa* growing on the edge of bunch-grass prairie.
12. *Andropogon scoparius* bunch-grass prairie.
13. *Calamovilfa* ridge.
14. Bunch-grass prairie with a few very low *Calamovilfa* ridges.
15. *Potentilla fruticosa* association.
16. A thicket of *Salix.*
17. A swale.
18. *Populus-Salix* ridge.
19. Heath.
20. Heath with blowouts and a little *Calamovilfa.*
21. *Scirpus americanus* association.

22. *Scirpus validus* association.
23. *Typha latifolia.*
24. *Castalia-Nymphaea* association.
25. *Potamogeton natans* association.
26. Little Dead River.
27. *Nymphaea advena.*
28. *Typha latifolia.*
29. *Scirpus validus* association.
30. *Scirpus americanus* association.
31. *Liatris spicata* prairie.
32. *Scirpus americanus* association.
33. *Panicum virgatum* ridge.
34. *Juncus torreyi* association.
35. *Liatris spicata* prairie.
36. *Juncus torreyi* association.
37. *Scirpus validus* association.
38. *Typha latifolia.*
39. *Scirpus americanus* association.
40. Elgin, Joliet and Eastern railway.
41. Swale, whose structure was exceedingly complex.
42. A ridge which had been cleared and was covered with weeds, including especially *Polygonum orientale* and *Helianthus annuus.*
43. *Liatris spicata* prairie.
44. *Phragmites-Typha* swamp, eighty feet wide.
45. *Scirpus validus* association.
46. *Scirpus americanus* association.
47. Chicago and North Western railway.
48. Cultivated land.
49. *Ulmus-Acer* association at the foot of the bluff.
50. Bluff covered for the most part with oak-hickory woods.

SECTION MADE ALONG THE LINE OF THE PEST-HOUSE ROAD BETWEEN WAUKEGAN AND BEACH, AUGUST, 1909

1. Lake Michigan.
2. Lower beach, devoid of plants.
3. Middle beach, bare except for an occasional *Xanthium.*
4. *Salix syrticola* fringing dune.
5. Depression.
6. Small *Populus-Salix* dunes.
7. *Andropogon scoparius* bunch-grass prairie.
8. *Calamovilfa* dune.

9. Bunch-grass prairie.
10. Heath represented by *Arctostaphylos.*
11. Bunch-grass prairie.
12. Heath of *Arctostaphylos.*
13. *Calamovilfa* dune.
14. Bunch-grass prairie.
15. Heath of *Arctostaphylos* and *Juniperus.*
16. *Potentilla fruticosa* association.
17. *Juncus torreyi* association.
18. *Cladium mariscoides* swale.
19. *Calamovilfa* dune, mostly supplanted by heath.
20. A suggestion of *Liatris spicata* prairie by *Tofieldia.*
21. Heath.
22. *Juncus torreyi.*
23. *Cladium* swale.
24. *Liatris spicata* prairie.
25. *Juncus torreyi* association.
26. *Cladium* swale.
27. *Liatris spicata* prairie.
28. *Scirpus americanus* association.
29. *Potamogeton* association.
30. *Juncus torreyi* association.
31. *Liatris spicata* prairie.
32. *Juncus torreyi* association.
33. *Scirpus americanus* association.
34. *Cladium mariscoides* association.
35. *Scirpus americanus* association.
36. *Scirpus validus* association.
37. *Nymphaea advena.*
38. Open water.
39. *Scirpus validus* association.
40. *Scirpus americanus* association.
41. *Liatris spicata* prairie.
42. *Cladium* swale.
43. *Liatris scariosa* association with blowouts.
44. *Scirpus americanus* association.
45. *Cladium* swale.
46. *Liatris spicata* prairie.
47. *Cladium* swale.
48. *Liatris scariosa* ridge with a few relic pines.
49. *Calamagrostis canadensis* association.

50. A ridge with *Calamovilfa, Betula alba papyrifera,* and *Juniperus.*
51. *Cladium* swale of considerable width.
52. *Scirpus americanus* association.
53. *Scirpus validus* association.
54. *Sagittaria latifolia.*
55. *Liatris spicata* prairie.
56. *Scirpus validus* association.
57. *Typha latifolia* association.
58. *Sagittaria latifolia.*
59. *Liatris spicata* prairie giving way to thicket.
60. *Scirpus validus* association.
61. *Typha latifolia.*
62. *Scirpus validus* association.
63. *Liatris spicata* prairie with a few relic pines.
64. *Scirpus validus* swale.
65. *Liatris spicata* prairie on a ridge.
66. *Scirpus validus* association.
67. *Liatris spicata* prairie.
68. *Scirpus validus* association.
69. Chicago and North Western railway.
70. *Typha latifolia.*
71. *Calamagrostis canadensis* association.
72. *Salix* thicket.
73. *Calamagrostis* association.
74. *Salix* thicket which has followed *Liatris spicata.*
75. *Scirpus validus* association.
76. *Phragmites-Typha* association.
77. *Scirpus validus* association.
78. *Salix* thicket.
79. *Scirpus fluviatilis.*
80. *Populus-Salix* thicket.
81. Bluff woods, of oaks and hickories for the most part.

A section taken north of Beach would show, behind the dune-complex, ridges of *Quercus velutina* alternating with thickets and with prairie for a distance of about 0.8 km. from the lake. Between the last ridge of oaks and the railway, areas of prairie alternate with areas of swamp. Sections taken farther north become simpler, and contain fewer and fewer associations until, near Kenosha, the bluff is cut into by the lake.

General Conclusions

Consideration of the foregoing data makes evident the successional relations of the three floral provinces represented in the Beach area. And what holds good for this area is applicable to northeastern Illinois and southeastern Wisconsin in general, as might naturally be expected. Over the greater part of this general region there is a greater extent of prairie than of forest, but in the Beach area, forests occupy about half the ground. The larger part of the forest is the deciduous forest of the southeastern center of dispersal.

Successions clearly show that there have been times in the past when each one of these provinces was more widely extended than is now the case. This is particularly true of the prairie and the conifer forest, for they are gradually being reduced in extent through natural causes which at the same time favor the increase of the deciduous forest. Aside from wave action the factors that tend toward the destruction of the deciduous forest are all connected with the inroads of man.

Before going further into detail, a recapitulation of the pertinent characteristics of the vegetation of the different floral provinces is in order.

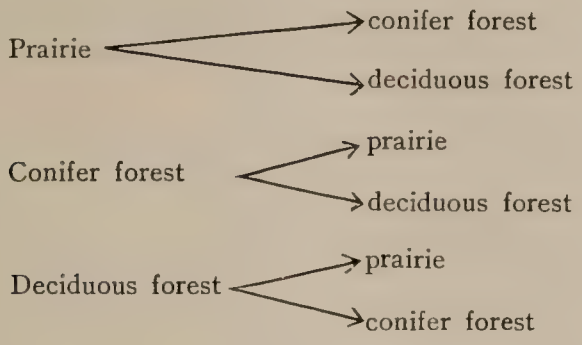
Prairie Province.—The vegetation is less than two meters, usually about one meter, in hight, consisting of grasses and herbs usually assembled very closely together, often forming sod. The plants will stand a considerable variation in the moisture content of the soil but require virtually the maximum amount of light.

Deciduous Forest Province.—The dominant plants are deciduous trees, in the more xerophytic associations, such as are represented in this region, rather openly assembled, giving all variation in shade, usually with little or no sod. The ground vegetation is open, and often consists of a number of plants whose showy flowers constitute the seasonal aspects. The seedlings are rather intolerant of shade, but otherwise develop very readily. Once established on this sandy soil, associations of this province are usually permanent.

Northeastern Conifer Forest Province.—The plants are evergreen trees or prostrate evergreen shrubs, growing in sandy soil in more or less closed assemblages. The denser assemblages of trees cast so much shade that all undergrowth is prohibited and the ground is carpeted with pine needles. Where the assemblages are more open, there are numerous herbaceous plants. With the exception of a very few local stations, the pines of this region are not reproducing themselves. On the other hand, the heath plants reproduce readily, by

seeds as well as through vegetative means, on the more xerophytic soils.

With these characteristics in mind, consideration can now be given to the different lines of succession that are theoretically possible between the associations of the three provinces. The possible successions are indicated below, and will be taken up in corresponding order.



As this region is nominally placed in the prairie on maps of vegetation (by Pound and Clements, Engler, Transeau, Sargent, and others), the successional relationships of the prairie will be taken up first. In this region the prairie should not be replaced by the conifer forest, as it is south of the natural range of that province. Locally, where the prairie sod has been accidentally broken, young pines are occasionally found, but as the occurrence is so plainly accidental, and taking into consideration other facts of the region, it is perfectly justifiable to say that in this region the prairie will never be succeeded by conifer forest.

In the case of the deciduous forest, matters are different. Prairie and deciduous forest are everywhere in juxtaposition, which results in the shading of the edges of the prairie. This occasions the gradual breaking up of the normally dense prairie growth, permitting the occurrence of open places in which the deciduous forest can readily take hold. Such succession is very slow. Occasionally an oak will effect ecesis in the body of the prairie itself—the result of accidental planting, probably by crows or jays. Once started, nothing but accident prevents the development of mature trees, which by their increasing shade modify the prairie radially and serve as a nucleus for the spread of the forest. As long as the prairie sod remains intact, however, this succession can not take place. Yet, notwithstanding the fact that things are changing slowly, it is apparent that, under

present climatic conditions, the prairie of this region will ultimately give place to the deciduous forest.

In dealing with the conifer forest province it must be kept in mind that the area is several (130) kilometers south of the southern limit of the province in eastern Wisconsin, and virtually no invasion by it into other provinces could be expected. The question is whether or not it can hold its own. In the case of the prairie this question is usually decided in the affirmative, as the prairie can not exist in the dense shade of the conifers. It spreads into the pines only when some of their number die. Then it takes possession of the open spaces and prevents reproduction of the pines, so that with the dying of the old trees the prairie is left supreme. (Fig. 2, Pl. LVI.)

Seedlings of the oak *Quercus velutina,* are present almost throughout the area of the pines, with the exception of the very densest parts. While usually only the oaks in the open places develop, the continual presence of seedling oaks under the pines means that whenever a pine dies, in a short time its place is occupied by a number of oak trees, under whose shade the seedling pines—few in number at best—can not develop. It is therefore clearly evident that in this region the remaining representatives of the conifer forest province will ultimately be replaced by trees, representative of the deciduous forest province.

These same general statements, slightly modified, hold true for the heath association, a member of the conifer forest province. The typical heath plants are somewhat more lenient in their ecological demands than the coniferous trees, which signifies, however, only that a much greater length of time will be necessary to effect their elimination from the region. As long as the prairie growth is fairly open, the heath and prairie plants thrive together, but a dense prairie growth is very efficient in choking out the heath. Heath plants are only fairly tolerant of shade; but as long as the open black oak woods prevail, the heath can readily persist in the open places. Greater shading eliminates bearberry (*Arctostaphylos*), but *Juniperus horizontalis* and especially *J. communis depressa* can exist even in the much denser shading of a bur oak (*Quercus macrocarpa*) woods. Here, however, they are etiolated in response to the diminution of light, and show the other characteristic modifications induced by shade, namely, broader, flatter leaves which spread more, making a looser and weaker growth.

The deciduous forest—now occupying nearly half of the Beach area—is the natural climatic floral province to be expected in this region with the present conditions of climate. In all natural suc-

cessions this province maintains its dominance. The prairie can not naturally supersede it because the climatic conditions are suitable for the development of forests, and the prairie, as a unit, can not make headway under shade. Conifers can not succeed the deciduous forest because they can not reproduce themselves in it.

In view of these facts, it is plainly evident that, under the present conditions of climate, the deciduous forest province is the dominant one in this region, and if left to itself in nature would ultimately occupy the entire region.

Summary

1. The Beach area is a strip of low sandy land bordering Lake Michigan in northeastern Illinois and southeastern Wisconsin. Its length is about 14 miles and its extreme width is a little over a mile. Its maximum elevation above Lake Michigan is less than 30 feet.

2. This region lies a little way south of the southern limits of the Northeastern Conifer Province, within an area of competition between the Prairie and Deciduous Forest provinces, in a climate which is favorable to tree growth.

3. During postglacial times the entire region was submerged, and within the past eighty years the region has at times been virtually inundated.

4. The region contains 55 plant associations, representing three plant provinces: Northeastern Conifer, Prairie, and Deciduous Forest.

5. A study of the successions between the different plant associations gives a very satisfactory understanding of plant dynamics.

6. The two fundamental starting-points for genetic series are the open water of Lake Michigan and of the streams that flow into it. The lines of succession commence with open water and proceed through stages of progressively increasing dryness, which culminates, in the Beach area proper, in the black oak association. The intermediate steps group themselves along several genetic lines.

7. Commencing with Lake Michigan, one genetic line extends from aquatic algae through associations inhabiting progressively drier soil in the depressions and swales between the ridges. Another line begins with the plants that inhabit the open beach, where they are exposed to extreme xerophtic conditions, because of a continual addition to the food in the soil, and advances to associations of an increasing number of species and a higher type of vegetative development. A third line commences in the streams with plants which are wholly

submerged, and proceeds through associations of plants which are progressively less hydrophytic to those which are mesophytic.

8. A change in the water-table level—whether brought about by special factors, as local erosion, blowing away or piling up of sand, or general factors, as periodical fluctuations in the level of Lake Michigan—very materially aids the plant dynamics in bringing about these successions.

9. The establishment of a genetic series may be initiated by nearly any of its lower members, while the advanced stages are dependent upon preceding associations for a foothold.

10. Favorable chances for invasion are usually readily taken advantage of, while the unfavorable periods of the lesser climatic cycles tend to produce adaptations to those conditions rather than a reversal of the normal line of succession.

11. Aquatic associations have a relatively greater number of individuals of a much smaller number of species than land associations.

12. Associations in the middle of a true genetic series are composed of a larger number of species than the associations towards the beginning or towards the end of the series.

13. Although most of the aquatic and semiaquatic plants are closely restricted within certain depths of water, their position in any given locality is determined by competition of associations rather than by the different physical requirements of the plants. The same relative arrangement is maintained within the limits of the requirements of the individual plants in different localities, even though the absolute conditions may vary greatly.

14. When associations within one formation are concerned, succession usually begins by the invasion of the secondary species of the invading association, and the succession may be said to be completed when the dominant species have made their appearance.

15. In the case of the invasion of an association of one formation into an area occupied by an association of another formation, invasion is effected by the dominant species with the subsequent appearance of the secondary species. Invasion of one formation into another takes place through the genetically lower, or pioneer associations.

16. In the Beach area, either the black oak or the prairie may displace the conifers; the prairie also gives way to the deciduous forest. Associations of the marsh habitats usually go through a prairie stage before becoming forested by deciduous trees.

List of the Species of Plants Growing on the Beach Area

This list is arranged in systematic order, with the collection numbers of those collected. The nomenclature is that of Gray's Manual, 7th edition. Synonyms are given in parentheses.

THALLOPHYTA

Chlamydomonas sp.?
Oscillatoria sp.?
Chara sp.? (3202)
(No other genera of algae were determined)

BRYOPHYTA

Riccia fluitans L. (3217)
Marchantia polymorpha L. (3151) Liverwort
Polytrichum juniperinum Willd. (2744) Moss
(No other species were determined)

PTERIDOPHYTA

Polypodiaceae. Fern Family.

Pteris aquilina L. Bracken Fern
Aspidium thelypteris (L.) Sw. (2501, 2801, 2929) Marsh Fern

Osmundaceae. Flowering Fern Family.

Osmunda regalis L. (O. spectabilis Willd.) (1652, 2765) Royal Fern

Equisetaceae. Horsetail Family.

Equisetum arvense L. Horsetail
Equisetum laevigatum A. Br. Scouring rush
Equisetum hiemale L. (3041) Scouring rush

SPERMATOPHYTA

Pinaceae. Pine Family.

Pinus strobus L. (2483, 2809, 2905) White Pine
Pinus laricio Poir. (2841, 2903) Austrian Pine
Pinus silvestris L. (3165, 3205) Scotch Pine
Pinus sp.
Larix decidua Mill. (2460, 2842) Tamarack

Juniperus communis depressa Pursh. (1659, 2843, 2907) Juniper
Juniperus horizontalis Moench. (1658) Procumbent Juniper
Juniperus virginiana L. (2910) Red Cedar

Typhaceae. Cattail Family.

Typha latifolia L. (3091) Cattail
Typha angustifolia L. (2824) Narrow-leaved Cattail
Typha latifolia x angustifolia (2915)

Sparganiaceae. Bur-reed Family.

Sparganium eurycarpum Engelm. (2831) Bur-reed

Naiadaceae. Pondweed Family.

Potamogeton natans L. Pondweed
Potamogeton foliosus niagarensis (Tuckerm.) Morong. (3246) Pondweed

Juncaginaceae. Arrow Grass Family.

Triglochin maritima L. (2515) Arrow Grass
Triglochin palustris L. (2867)

Alismaceae. Water-plantain Family.

Sagittaria latifolia Willd. (2908) Arrowleaf
Sagittaria heterophylla rigida (Pursh) Engelm. Arrowleaf
Alisma plantago-aquatica L. (2902) Water-plantain

Hydrocharitaceae. Frog's Bit Family.

Elodea canadensis Michaux. Water-weed

(Gramineae) Poaceae. Grass Family.

Andropogon scoparius Michx. (2921) Beard Grass
Andropogon furcatus Muhl. (2940) Beard Grass
Sorghastrum nutans (L.) Nash. (2966)
Digitaria sanguinalis (L.) Scop. (3257) Finger Grass, Crab Grass
Panicum capillare L. (3232) Witch Grass, Old-witch Grass
Panicum virgatum L. (2938) Switch Grass
Panicum huachucae Ashe. (3224)
Panicum scribnerianum Nash. (3065)
Echinochloa crusgalli (L.) Beauv. (3209) Barnyard Grass
Cenchrus carolinianus Walt. (2980) Sandbur
Leersia oryzoides (L.) Sw. (2985) Rice Cut-grass

Hierochloe odorata (L.) Wahlenb. Vanilla Grass
Stipa spartea Trin. (2464) Porcupine Grass
Aristida purpurascens Poir. (3260)
Phleum pratense L. (3064) Timothy
Sporobolus cryptandrus (Torr.) A. Gray. (3255) Drop-seed
Sporobolus heterolepis A. Gray. (3223)
Agrostis alba L. Red Top.
Calamovilfa longifolia (Hook.) Hack. (2920)
Calamagrostis canadensis (Michx.) Beauv. (2823) Reed Grass, Blue-joint Grass
Ammophila arenaria (L.) Link. (3201, 3281) Beach Grass
Koeleria cristata (L.) Pers. (2467, 2763)
Spartina michauxiana Hitchc. (2913) Slough Grass
Phragmites communis Trin. (3166) Reed
Poa compressa L. (2860) English Blue Grass
Poa pratensis L. (3037) Blue Grass, June Grass, Spear Grass, Kentucky Blue Grass
Glyceria nervata (Willd.) Trin. (2810)
Festuca octoflora Walt. (2468) Fescue Grass
Bromus tectorum L.
Bromus incanus (Shear) Hitchc. (3173)
Bromus kalmii Gray. (2762, 2795) Wild Chess
Elymus canadensis L. (2879, 2880) Wild Rye

Cyperaceae. Sedge Family.

Cyperus rivularis Kunth. (2986) Sedge
Cyperus schweinitzii Torr. (3149)
Cyperus filiculmis macilentus Fernald. (3147)
Dulichium arundinaceum (L.) Britton. (3261)
Eleocharis acuminata (Muhl.) Nees. Spike Rush
Eleocharis intermedia (Muhl.) Schultes. (2926)
Fimbristylis castanea (Michx.) Vahl. (2814, 2863)
Scirpus americanus Pers. (2508, 2856.) 3-angle Bulrush
Scirpus validus Vahl. (2862, 2865) Great Bulrush
Scirpus occidentalis (Wats.) Chase. (Collected by Dr. H. A. Gleason and determined by Mrs. Chase.)
Scirpus fluviatilis (Torr.) Gray. (2785) River Bulrush
Scirpus rubrotinctus Fernald. (3059)
Scirpus atrovirens Muhl. (2770)
Scirpus lineatus Michx. (2836)
Eriophorum angustifolium Roth. (E. polystachion L. in part) (1669, 2523) Cotton Grass

Rynchospora alba (L.) Vahl. (Collected by L. M. Umbach, July 31, 1909.)
Rynchospora capillacea leviseta E. J. Hill. (2851, 2925) Beak Rush
Cladium mariscoides (Muhl.) Torr. (2857, 2868, 2916) Twig Rush
Scleria triglomerata Michx. (2772) Nut Rush
Scleria verticillata Muhl. (3210)
Carex bebbii Olney. Sedge
Carex aurea Nutt. (2503)
Carex buxbaumii Wahl. (2504)
Carex comosa Boott. (2917)
Carex crawei Dewey. (2502, 2821)
Carex filiformis L.
Carex hystericina Muhl. (2787)
Carex lanuginosa Michx. (3027)
Carex muhlenbergii Schk. (2465, 3163)
Carex oederi pumila (Cosson & Germain) Fernald. (C. viridula Michx.) (2509, 2517)
Carex riparia W. Curtis. (2786)
Carex stipata Muhl. (3052)
Carex stricta Lam. (2498)
Carex trisperma Dewey. (Collected by Dr. H. A. Gleason)
Carex umbellata Schk. (2474)

Araceae. Arum Family.

Symlocarpus foetidus (L.) Nutt. (3062) Skunk Cabbage
Acorus calamus L. (2766, 2897) Sweet Flag

Lemnaceae. Duckweed Family.

Lemna minor L. (3218) Duckweed

Commelinaceae. Spiderwort Family.

Tradescantia reflexa Raf. (3022) Spiderwort

Pontederiaceae. Pickerel-weed Family.

Pontederia cordata L. Pickerel-weed

Juncaceae. Rush Family.

Juncus bufonius L. (2782) Rush
Juncus tenuis Willd.
Juncus balticus littoralis Engelm. (2882, 2923, 3250)
Juncus canadensis J. Gay. (2848, 2850)
Juncus torreyi Coville. (2869, 2909)

Juncus alpinus insignis Fries.
Luzula campestris multiflora (Ehrh.) Celak. (3046) Wood Rush

Liliaceae. Lily Family.

Tofieldia glutinosa (Michx.) Pers. (2789, 2846, 2912) False Asphodel
Allium cernuum Roth. (2895) Nodding Onion
Lilium canadense L. (2828) Wild Yellow Lily
Lilium philadelphicum andinum (Nutt.) Ker. (2764, 2777, 2793, 2807, 2947, 2933) Wood Lily
Asparagus officinalis L. (3023) Asparagus
Smilacina stellata (L.) Desf. (2492) False Solomon's Seal
Maianthemum canadense Desf. (2484, 2488) One-leaved Solomon's Seal
Polygonatum biflorum (Walt.) Ell. Small Solomon's Seal
Polygonatum commutatum (R. & S.) Dietr. (3025) Great Solomon's Seal
Aletris farinosa L. (2748, 2835) Colic Root
Smilax ecirrhata (Engelm.) Watson. Carrion Flower
Smilax hispida Muhl. Green Brier

Dioscoreaceae. Yam Family.

Dioscorea paniculata Michx. (3113) Yam

Amaryllidaceae. Amaryllis Family.

Hypoxis hirsuta (L.) Coville. (2519) Star Grass

Iridaceae. Iris Family.

Iris versicolor L. (2521) Iris
Sisyrinchium sp.? (2485, 2514, 2855, 3018) Blue-eyed Grass

Orchidaceae. Orchid Family.

Cypripedium hirsutum Mill. (C. reginae Walt.) (2961) Showy Lady's Slipper
Habenaria hyperborea (L.) R. Br.
Habenaria dilatata (Pursh) A. Gray. (2753, 2797)
Habenaria clavellata (Michx.) Spreng. (2884)
Habenaria leucophaea (Nutt.) A. Gray. (2800, 2840) White Fringed Orchid
Habenaria psycodes (L.) Sw. (3176, 3182) Purple Fringed Orchid
Pogonia ophioglossoides (L.) Ker. (2754, 2804)
Calopogon pulchellus (Sw.) R. Br. (2747)

Spiranthes cernua (L.) Richard. (2992, 2971) Ladies' Tresses
Liparis loeselii (L.) Richard. (2507) Twayblade

Salicaceae. Willow Family.

Salix amygdaloides Anders. (3172, 3175) Peach-leaved Willow
Salix lucida Muhl. (2900, 3060, 3170) Shining Willow
Salix serissima (Bailey) Fernald. (2995) Autumn Willow
Salix longifolia Muhl. (3080) Sand-bar Willow
Salix cordata Muhl.
Salix glaucophylla Bebb. (3033, 3036)
Salix syrticola Fernald. (2459, 3156)
Salix pedicellaris Pursh. (3174)
Salix discolor Muhl. Pussy Willow
Salix candida Fluegge. (2758) Hoary Willow
Populus tremuloides Michaux. (3104) Trembling Aspen
Populus candicans Aiton. (2780, 3155) Balm of Gilead
Populus deltoides Marsh. (3035) Cottonwood

Juglandaceae. Walnut Family.

Juglans nigra L. (3117) Black Walnut
Carya ovata (Mill.) K. Koch. (3120) Shag-bark Hickory

Betulaceae. Birch Family.

Betula alba papyrifera (Marsh.) Spach. (3097) White Birch
Betula pumila L. (2493, 2500, 2813) Swamp Birch

Fagaceae. Beech Family.

Quercus alba L. (3125) White Oak
Quercus macrocarpa Michaux. (3119) Bur Oak
Quercus velutina Lam. (2981) Black Oak

Santalaceae. Sandalwood Family.

Comandra umbellata (L.) Nutt. (2790) Bastard Toad-flax

Polygonaceae. Buckwheat Family.

Rumex britannica L. (3231) Great Water Dock
Rumex acetosella L. (3063) Sheep Sorrel
Rumex crispus L. (3095) Curled Dock
Polygonum tenue Michaux. (3206) Smartweed
Polygonum lapathifolium L. (=P. incarnatum Ell.) (3227)
Polygonum amphibium hartwrightii (A. Gray) Bissell. (3179)
Polygonum muhlenbergii (Meisn.) Wats. (3247)

Polygonum pennsylvanicum L. (3238)
Polygonum acre HBK. (3241)
Polgonum persicaria L. (3253) Lady's Thumb
Polygonum hydropiperoides Michaux. Mild Water Pepper

Chenopodiaceae. Goosefoot Family.

Cycloloma atriplicifolium (Spreng.) Coulter. (2975) Winged Pigweed
Chenopodium album L. Lamb's Quarters
Corispermum hyssopifolium L. (3226) Bug-seed
Salsola kali tenuifolia G. F. W. Mey. (2974) Russian Thistle

Amaranthaceae. Amaranth Family.

Acnida tuberculata subnuda Wats. Water Hemp

Caryophyllaceae. Pink Family.

Arenaria stricta Michaux. (2510) Sandwort
Silene antirrhina L. (2449) Sleepy Catchfly
Silene stellata (L.) Aiton f. (3267) Starry Campion

Ceratophyllaceae. Hornwort Family.

Ceratophyllum demersum L. (Collected by Dr. H. A. Gleason.)

Nymphaeaceae. Water Lily Family.

Nymphaea advena Aiton. (3015) Yellow Water Lily
Castalia tuberosa (Paine) Greene. (3204) White Water Lily

Ranunculaceae. Crowfoot Family.

Ranunculus aquatilis capillaceus DC. (Batrachium trichophyllum Bosch) (3014) White Water Crowfoot
Ranunculus delphinifolius Torrey. Yellow Water Crowfoot
Ranunculus sceleratus L. Cursed Crowfoot
Ranunculus pennsylvanicus L. f. (3244) Bristly Crowfoot
Anemone cylindrica A. Gray. (2761) Anemone
Anemone virginiana L. (3140)
Anemone canadensis L. (3029)

Berberidaceae. Barberry Family.

Podophyllum peltatum L. (3056) May Apple

(Cruciferae) Brassicaceae. Mustard Family.

Draba caroliniana Walt. (2477)
Lepidium apetalum Willd. (3101) Peppergrass

Cakile edentula (Bigel.) Hook. (2976) Sea Rocket
Sisymbrium officinale leiocarpum DC. (3251) Hedge Mustard
Radicula palustris (L.) Moench. Water Cress
Arabis lyrata L. (2511) Rock Cress

Droseraceae. Sundew Family.

Drosera rotundifolia L. (2803) Sundew

Crassulaceae. Orpine Family.

Penthorum sedoides L. (3248) Ditch Stonecrop

Saxifragaceae. Saxifrage Family.

Heuchera hispida Pursh. (1663, 2451) Alum Root
Parnassia caroliniana Michaux. (2959) Grass of Parnassus

Rosaceae. Rose Family.

Spiraea salicifolia L. (2888) Spiraea
Pirus malus L. (Malus malus (L.) Britton) Apple
Crataegus punctata Jacq. (3110) Thorn Apple
Fragaria virginiana Duchesne. (2455, 2480, 2773) Strawberry
Potentilla arguta Pursh. (2829)
Potentilla palustris (L.) Scop. (Comarum palustre L.) (3178) Marsh Five-finger
Potentilla fruticosa L. (Dasiphora fruticosa (L.) Rydb.) (2853, 2973) Shrubby Cinquefoil
Potentilla anserina L. (Argentina anserina (L.) Rydb.) (2518, 2924 Silver Weed
Geum canadense Jacq. (3107) Avens
Rubus occidentalis L. Black Raspberry
Agrimonia gryposepala Wallr. (3278) Agrimony
Rosa blanda Aiton. (3262) Smooth Wild Rose
Rosa carolina L. Swamp Wild Rose
Rosa humilis Marsh. (3167)
Prunus serotina Ehrh. (3028) Black Cherry
Prunus virginiana L. (3024) Choke Cherry
Prunus pumila L. (2458, 2745) Sand Cherry

Leguminosae. Pulse Family.

Baptisia leucantha Torr. & Gray. (2750) False Indigo
Lupinus perennis L. (2452) Wild Lupine
Trifolium pratense L. Red Clover
Trifolium repens L. White Clover

Trifolium hybridum L. Alsike Clover
Melilotus alba Desr. White Sweet Clover
Amorpha canescens Pursh. (2894) Lead Plant
Petalostemum purpureum (Vent.) Rydb. (2872) Purple Prairie Clover
Petalostemum purpureum f. arenarium Gates, forma nova (2922) Sand-Prairie Clover
Petalostemum candidum Michaux. (2832, 2871) White Prairie Clover
Astragalus canadensis L. (3042) Milk Vetch
Desmodium illinoense A. Gray. Tick Trefoil
Lespedeza capitata Michaux. (2962) Bush Clover
Vicia americana Muhl. Vetch
Lathyrus palustris myrtifolius (Muhl.) A. Gray. (2822) Vetchling
Lathyrus maritimus (L.) Bigel. (3157) Beach Pea
Lathyrus venosus Muhl. (3016)
Apios tuberosa Moench. (2946) Wild Bean
Amphicarpa monoica (L.) Ell. Hog Peanut

Linaceae. Flax Family.

Linum virginianum L. (2833, 2845) Flax
Linum sp.

Oxalidaceae. Wood Sorrel Family.

Oxalis stricta L. (3230) Wood Sorrel

Geraniaceae. Geranium Family.

Geranium maculatum L. (3044) Wild Geranium
Geranium carolinianum L. (3152)

Rutaceae. Rue Family.

Ptelea trifoliata L. (3229) Hop Tree

Polygalaceae. Milkwort Family.

Polygala polygama Walt. (2768) Milkwort
Polygala sanguinea L. (2948)
Polygala verticillata L. (2883)

Euphorbiaceae. Spurge Family.

Euphorbia polgygonifolia L. (2967) Seaside Spurge
Euphorbia maculata L. (3258) Milk Purslane
Euphorbia corollata L. (2852, 2892) Flowering Spurge

Anacardiaceae. Cashew Family.

Rhus typhina L. Staghorn Sumac
Rhus toxicodendron L. (2506, 2805) Poison Ivy
Rhus toxicodendron radicans (L.) Torrey. Climbing Poison Ivy

Celastraceae. Staff Tree Family.

Celastrus scandens L. Bittersweet

Aceraceae. Maple Family.

Acer negundo L. Box Elder

Balsaminaceae. Touch-me-not Family.

Impatiens biflora Walt. (2968) Spotted Touch-me-not

Rhamnaceae. Buckthorn Family.

Rhamnus alnifolia L'Her. (2486) Buckthorn
Ceanothus americanus L. (3162) New Jersey Tea
Ceanothus ovatus Desf. (1656, 2470, 2812) Red-root

Vitaceae. Vine Family.

Psedera quinquefolia (L.) Greene. Virginia Creeper
Vitis vulpina L. (2930) River-bank Grape

Tiliaceae. Linden Family.

Tilia americana L. (3098) Basswood

Hypericaceae. St. John's-wort Family.

Hypericum kalmianum L. (2462, 2844) Kalm's St. John's-wort
Hypericum sp.
Hypericum virginicum L. (Triadenum virginicum (L.) Raf.) (2963) Marsh St. John's-wort

Cistaceae. Rockrose Family.

Helianthemum majus BSP (2752) Frostweed
Lechea villosa Ell. (2956) Pinweed
Lechea leggettii Britton & Hollick. (2889, 2932, 2955)

Violaceae. Violet Family.

Viola papilionacea Pursh. (2448) Violet
Viola sagittata Aiton (=V. subsagittata Greene). (2481, 2839, 3161) Violet

Cactaceae. Cactus Family.

Opuntia rafinesquii Engelm. (2802) Prickly Pear

Lythraceae. Loosestrife Family.

Lythrum alatum Pursh. (3159) Loosestrife

Onagraceae. Evening Primrose Family.

Ludvigia palustris (L.) Ell. (Isnardia palustris L.) (2898) Water Purslane
Epilobium angustifolium L. (2759) Fireweed
Epilobium densum Raf. (2989, 3236) Willow-herb
Oenothera biennis L. Evening Primrose
Oenothera rhombipetala Nutt. (3158)

Haloragidaceae. Water Milfoil Family.

Myriophyllum verticillatum L. Water Milfoil
Proserpinaca palustris L. (3215) Mermaid-weed

Araliaceae. Ginseng Family.

Aralia nudicaulis L. Wild Sarsaparilla

Umbelliferae. Parsley Family.

Eryngium yuccifolium Michaux. (2886) Rattlesnake Master
Sanicula marilandica L. (3021) Black Snakeroot
Cicuta bulbifera L. (3234). Bulbiferous Water Hemlock
Cicuta maculata L. (3111) Water Hemlock
Zizia aurea (L.) Koch. (2476) Golden Alexanders
Heracleum lanatum Michaux. (3123) Cow Parsnip
Oxypolis rigidior (L.) Coulter & Rose. (2934) Cowbane

Cornaceae. Dogwood Family.

Cornus stolonifera Michaux. (2505, 2757, 3032) Red-osier Dogwood

Ericaceae. Heath Family.

Arctostaphylos uva-ursi (L.) Spreng. (2491) Bearberry

Primulaceae. Primrose Family.

Lysimachia thyrsiflora L. (Naumburgia thyrsiflora (L.) Duby) (2520) Tufted Loosestrife
Steironema quadiflorum (Sims) Hitchcock. (2873)
Dodecatheon meadia L. (2450) Shooting Star

Gentianaceae. Gentian Family.

Gentiana crinita Froel. Fringed Gentian
Gentiana procera Holm. (2977, 2997, 3284, 3287) Small Fringed Gentian
Gentiana andrewsii Griseb. (3271) Closed Gentian
Menyanthes trifoliata L. (3177) Buckbean

Apocynaceae. Dogbane Family.

Apocynum androsaemifolium L. (3114) Spreading Dogbane
Apocynum cannabinum hypericifolium (Ait.) A. Gray. Indian Hemp

Asclepiadaceae. Milkweed Family.

Asclepias tuberosa L. (2781) Butterfly-weed
Asclepias purpurascens L. (2779) Purple Milkweed
Asclepias incarnata L. (2896) Swamp Milkweed
Ascelpias syriaca L. (3088) Common Milkweed
Ascelpias amplexicaulis Sm. (2746)
Acerates viridiflora Ell. Green Milkweed
Acerates viridiflora lanceolata (Ives) A. Gray. (2806, 2808) Sand Green Milkweed

Convolvulaceae. Convolvulus Family.

Convolvulus sepium L. (3150) Hedge Bindweed

Polemoniaceae. Polemonium Family.

Phlox glaberrima L. (2791, 2837, 2991) Phlox
Phlox pilosa L. (2456) Phlox

Boraginaceae. Borage Family.

Lithospermum gmelini (Michx.) Hitchc. (2490, 2776) Puccoon
Lithospermum angustifolium Michaux. (1655, 3017) Puccoon

Verbenaceae. Vervain Family.

Verbena hastata L. (3211) Blue Vervain

Labiatae. Mint Family.

Isanthus brachiatus (L.) BSP. (3242) False Pennyroyal
Scutellaria galericulata L. (2756) Skullcap
Scutellaria parvula Michaux. (2461) Small Skullcap
Nepeta cataria L. (3136) Catnip
Prunella vulgaris L. Self-heal

Monarda fistulosa L. (3168) Wild Bergamot
Monarda mollis L.
Monarda punctata L. (2939) Horse Mint
Satureja glabra (Nutt.) Fernald. (2788, 2861) Calamint
Pycnanthemum virginianum (L.) Durand & Jackson. (2874) Mountain Mint
Lycopus sp.? (3243)
Lycopus americanus Muhl. (2899, 2935) Water Horehound
Mentha arvensis canadensis (L.) Briquet. Mint

Solanaceae. Nightshade Family.

Solanum nigrum L. Common Nightshade
Physalis virginiana Mill. (2463) Ground Cherry

Scrophulariaceae. Figwort Family.

Verbascum thapus L. (3259) Mullen
Linaria vulgaris Hill. Butter and Eggs
Scrophularia leporella Bicknell. (3092) Figwort
Chelone glabra L. (3269) Turtlehead
Veronica virginica L. (2927) Culver's-root
Veronica anagallis-aquatica L. (3239) Water Speedwell
Gerardia pedicularia L. Gerardia
Gerardia grandiflora Benth.
Gerardia paupercula (A. Gray) Britton. (2970)
Gerardia skinneriana Wood. (2942, 2964)
Gerardia tenuifolia Vahl. (3212) Slender Gerardia
Castilleja coccinea (L.) Spreng. (2479) Scarlet Painted Cup
Castilleja sessiliflora Pursh. (2466, 2751, 2811) Painted Cup
Pedicularis canadensis L. (2496) Common Lousewort
Pedicularis lanceolata Michaux. (3235) Lousewort

Lentibulariaceae. Bladderwort Family.

Utricularia vulgaris americana A. Gray. (3180) Bladderwort
Utricularia cornuta Michaux. (2847)

Orobanchaceae. Broom-rape Family.

Orobanche fasciculata Nutt. (2482, 2487) Broom-rape

Bignoniaceae. Bignonia Family.

Catalpa speciosa Warder. (3169) Catalpa

Plantaginaceae. Plantain Family.

Plantago major L. Common Plantain
Plantago rugelii Dcne.

Rubiaceae. Madder Family.

Galium boreale L. (2767) Northern Bedstraw
Galium trifidum L. (3237) Bedstraw
Cephalanthus occidentalis L. Buttonbush

Caprifoliaceae. Honeysuckle Family.

Lonicera dioica L. (2453) Honeysuckle
Viburnum lentago L. (3094) Sweet Viburnum
Sambucus canadensis L. (3116) Elder

Valerianaceae. Valerian Family.

Valeriana edulis Nutt. (1666) Valerian

Cucurbitaceae. Gourd Family.

Echinocystis lobata (Michx.) Torr. & Gray. Wild Cucumber

Campanulaceae. Bluebell Family.

Campanula aparinoides Pursh. (2885) Marsh Bluebell

Lobeliaceae. Lobelia Family.

Lobelia cardinalis L. (3214) Cardinal-flower
Lobelia siphilitica L. (2993) Great Lobelia
Lobelia spicata Lam. (2818) Spiked Lobelia
Lobelia kalmii L. (2919) Kalm's Lobelia

Compositae. Composite Family.

Vernonia fasciculata Michaux. (3213) Ironweed
Eupatorium purpureum maculatum (L.) Darl. (2950) Jo-Pye Weed
Eupatorium perfoliatum L. (2951) Boneset
Liatris cylindracea Michaux. (2943) Blazing Star
Liatris scariosa Willd. (2958) Blazing Star
Liatris spicata (L.) Willd. (2937, 2928) Blazing Star
Solidago speciosa Nutt. Goldenrod
Solidago speciosa angustata T. & G. (3265) Goldenrod
Solidago arguta Aiton. Goldenrod
Solidago nemoralis Aiton. (3273) Goldenrod
Solidago canadensis L. Goldenrod

Solidago serotina Ait. (2983, 3153)
Solidago rigida L.
Solidago ohioensis Riddell. (2988)
Solidago riddellii Frank.
Solidago graminifolia (L.) Salisb. (Euthamia graminifolia (L.) Nutt.) (3233)
Solidago spp.
Aster macrophyllus L. (3128) Aster
Aster novae-angliae L. (3263)
Aster sericeus Vent. (3154)
Aster azureus Lindl. (3268)
Aster ericoides L.
Aster multiflorus Ait. (3164)
Aster dumosus L. (3208, 3221)
Aster paniculatus Lam.
Aster salicifolius Ait.
Aster umbellatus Mill. (Doellingeria umbellata (Mill.) Nees) (2949)
Aster ptarmicoides T. & G. (2944, 2957)
Aster spp.
Erigeron philadelphicus L. (3020) Fleabane
Erigeron annuus (L.) Persoon. Daisy Fleabane
Erigeron ramosus (Walt.) BSP. (3090) Daisy Fleabane
Erigeron canadensis L. (Leptilon canadense (L.) Britton) (3256) Horse-weed
Erigeron divaricatus Michx. (Leptilon divaricatum Raf.) (3254)
Antennaria sp. Everlasting
Anaphalis margaritacea (L.) B. & H. (2990) Pearly Everlasting
Silphium terebinthinaceum Jacq. (3216) Prairie Rosin-weed
Silphium integrifolium Michaux. (2893) Rosin-weed
Ambrosia artemisiaefolia L. (3274) Ragweed
Xanthium commune Britton. (3228) Cocklebur
Rudbeckia subtomentosa Pursh. (2890) Cone-flower
Rudbeckia hirta L. (2830) Black-eyed Susan
Lepachys pinnata (Vent.) T. & G. (2891) Cone-flower
Helianthus occidentalis Riddell. (2965) Sunflower
Helianthus occidentalis illinoensis (Gleason) Gates. (2774, 2887, 2936)
Helianthus grosseserratus Martens
Helianthus maximiliani Schrad. (3282)
Helianthus divaricatus L. (2954)
Helianthus strumosus L.
Helianthus spp.

Coreopsis lanceolata L. (2478) Tickseed
Coreopsis lanceolata villosa Michaux. (2817)
Coreopsis palmata Nuttall. (3148)
Bidens vulgata Greene. Stick-tight
Bidens trichosperma tenuiloba (A. Gray) Britton. (2982) Tickseed Sunflower
Helenium autumnale L. (2984) Sneezeweed
Achillea millefolium L. (2760) Yarrow
Artemisia caudata Michaux. (2972) Wormwood
Cacalia tuberosa Nutt. (3249) Indian Plantain
Senecio balsamitae Muhl. (2512, 3031) Ragwort
Cirsium pitcheri (Torr.) T. & G. (2866) Pitcher's Thistle
Cirsium muticum Michaux. (2953) Swamp Thistle
Cirsium arvense (L.) Scop. (3245) Canada Thistle
Krigia amplexicaulis Nutt. (2499) False Dandelion
Taraxacum erythrospermum Andrz. Red-seeded Dandelion
Lactuca canadensis L. Wild Lettuce
Prenanthes racemosa Michaux. (3283) Rattlesnake-root
Prenanthes alba L. White Rattlesnake-root
Hieracium canadense Michaux. (2945) Hawkweed
Hieracium aurantiacum L. (2826) Orange Hawkweed. Though not occurring on the beach proper, but in the oak woods back of the Glenwood ridge, this is inserted here on account of the extension of its westward limit.

The following additional plants, although they were found within the limits of the region, were limited in distribution to the dump heaps and railway ballast.

Abutilon theophrasti Medic. Velvet Leaf
Agropyron repens (L.) Beauv. Couch Grass
Amaranthus retroflexus L. Pigweed
Ambrosia psilostachya DC. Ragweed
Anthemis cotula L. Dog Fennel
Arctium minus Bernh. Burdock
Brassica arvensis (L.) Ktze. Mustard
Capsella bursa-pastoris (L.) Medic. Shepherd's Purse
Eragrostis purshii Schrad.
Erechtites hieracifolia (L.) Raf. Fireweed
Helianthus annuus L. Sunflower
Helianthus atrorubens L. (3219) Sunflower
Hordeum jubatum L. (3040) Squirrel-tail Grass
Lactuca pulchella (Pursh) DC. (3220) Blue Lettuce

Lactuca scariola L. Prickly Lettuce
Lithospermum officinale L. (2784) Puccoon
Melilotus officinalis (L.) Lam. Yellow Sweet Clover
Panicum miliaceum L. (3207) Millet
Polanisia graveolens Raf.
Polygonum orientale L. (3279) Prince's Feather
Polygonum aviculare L. Knotweed
Setaria glauca (L.) Beauv. Yellow Foxtail Grass
Setaria viridis (L.) Beauv. Green Foxtail Grass
Sisymbrium officinale (L.) Scop. (2819) Hedge Mustard
Solanum dulcamara L. (3086) Bittersweet
Sonchus oleraceus L. Sow Thistle
Stellaria aquatica (L.) Scop. (2820) Water Chickweed
Tanecetum vulgare L. Tansy

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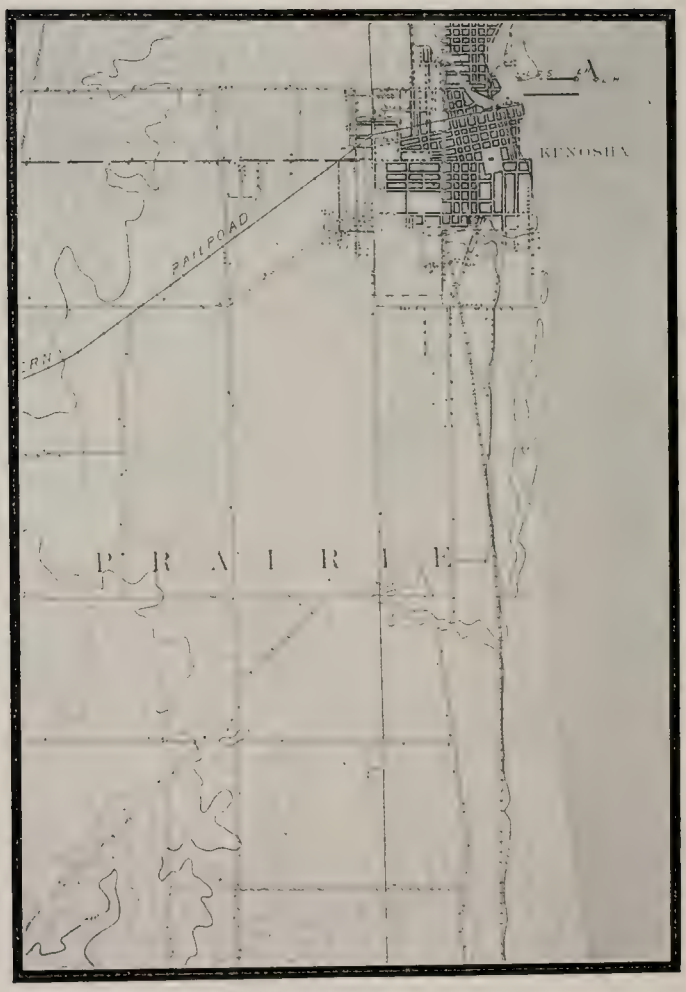
ERRATA

Page 256, line 3 of table, for Dr. H. *M.* Pepoon read Dr. H. *S.* Pepoon.
Page 278, line 16, rhizomes should be in Roman type.
Page 315, line 10, for *Apocynum* read *Apocynum*.
Page 351, line 4 from bottom, for *xerophitic* read *xerophytic*.
Page 356, line 14 from bottom, for *Symlocarpus* read *Symplocarpus*.
Page 365, line 14, for *thapus* read *thapsus*.
Plate XXXIX, for *Calamogrostis* read *Calamagrostis*.
Plate LIV, exchange places of cuts, but not the legends.

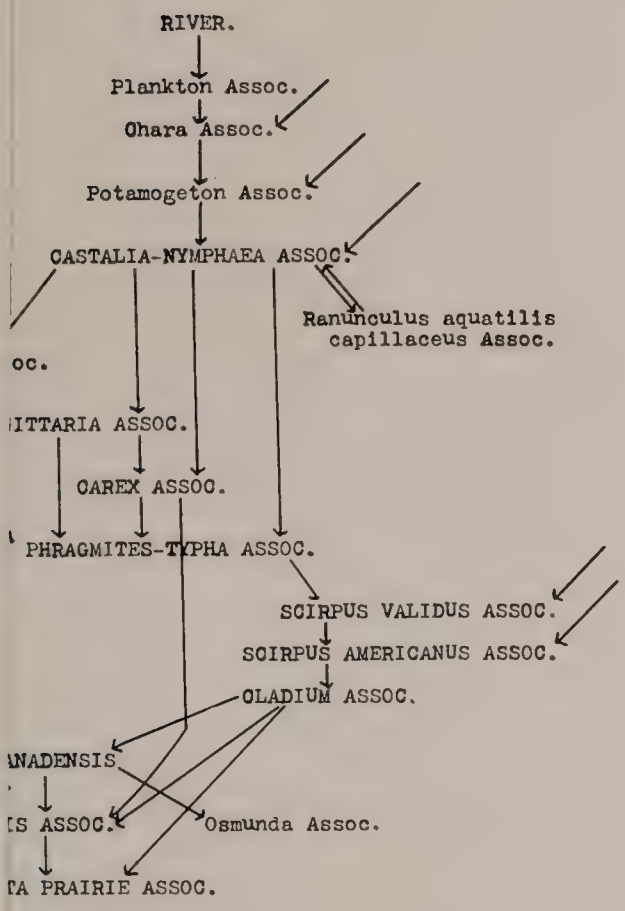
Plate XXXVII.

General map of the southern part of the Beach area.

Plate XXXVIII.



General map of the northern part of the Beach area.



n showing the successions exhibited between
associations in the Beach Area, Illinois.
primary successions.
secondary successions due to clearing,
burning or other disturbing factors.
letters denote the important associations.

FGA

PLATE XXXIX.

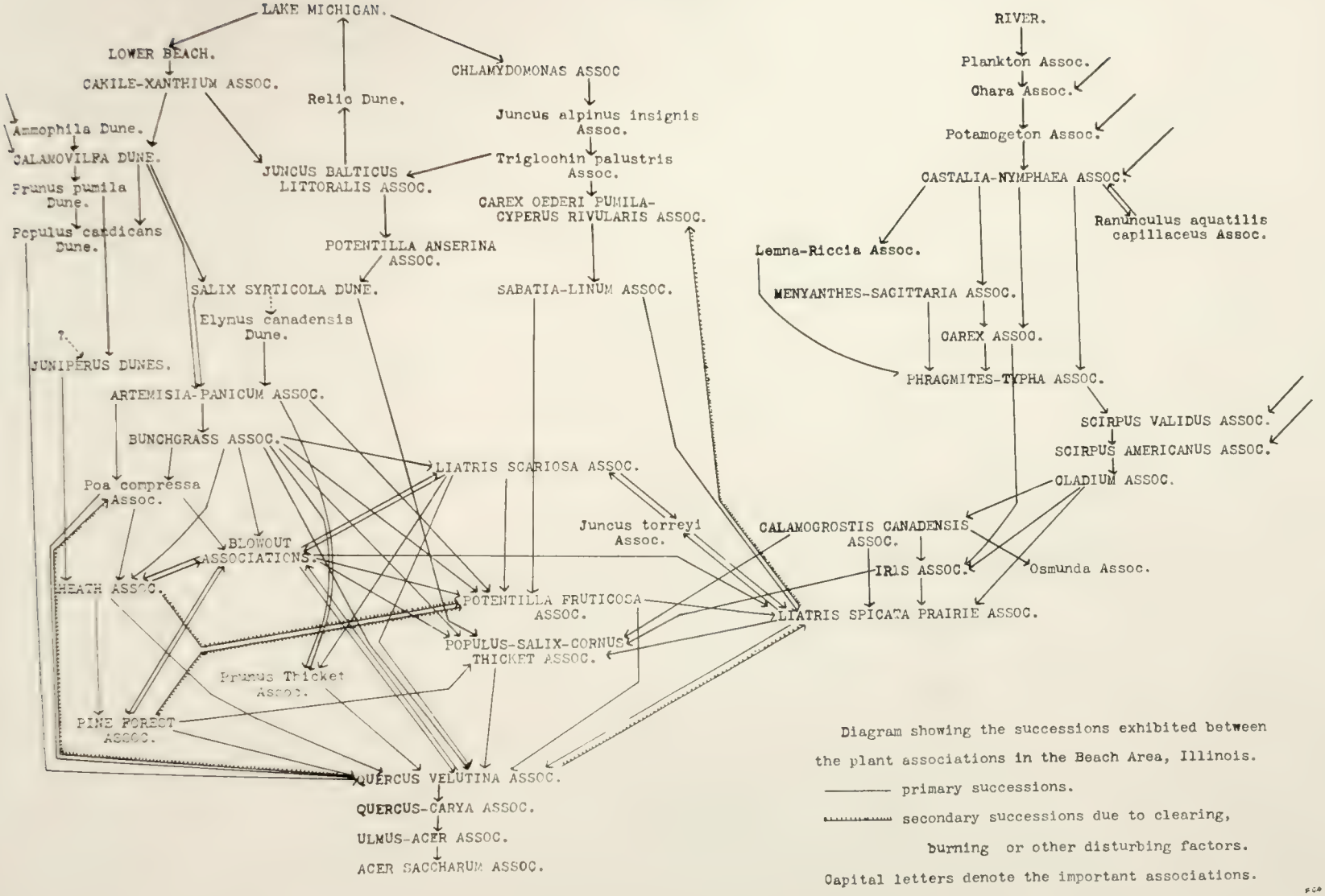


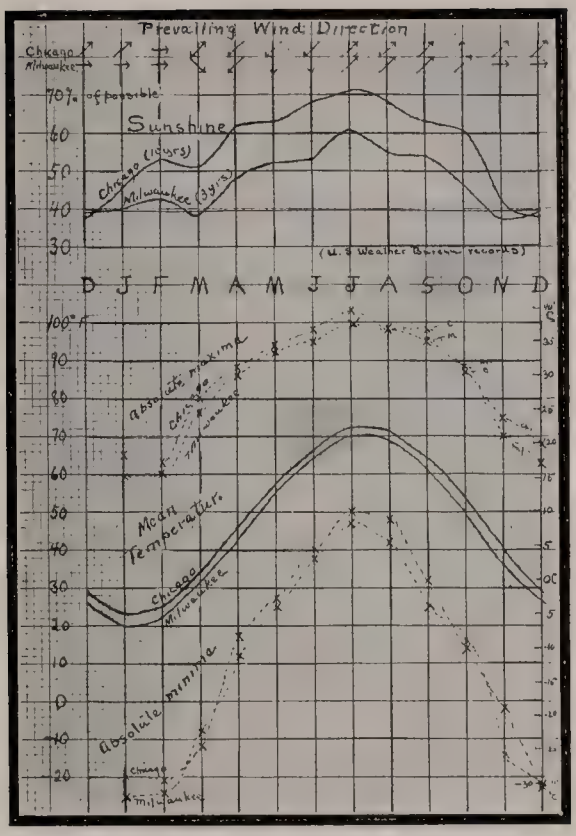
Diagram showing the successions exhibited between the plant associations in the Beach Area, Illinois.

——— primary successions.

..... secondary successions due to clearing, burning or other disturbing factors.

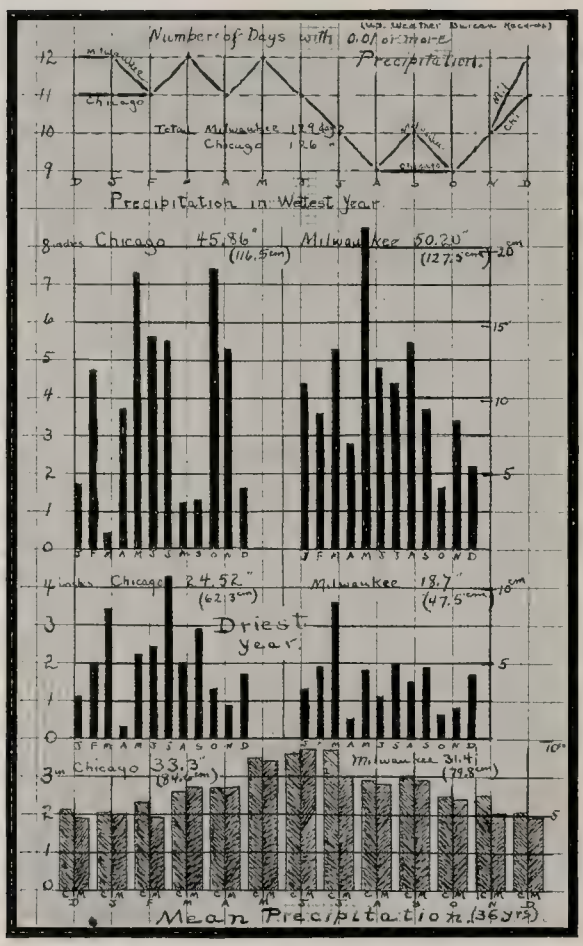
Capital letters denote the important associations.

Plate XL.



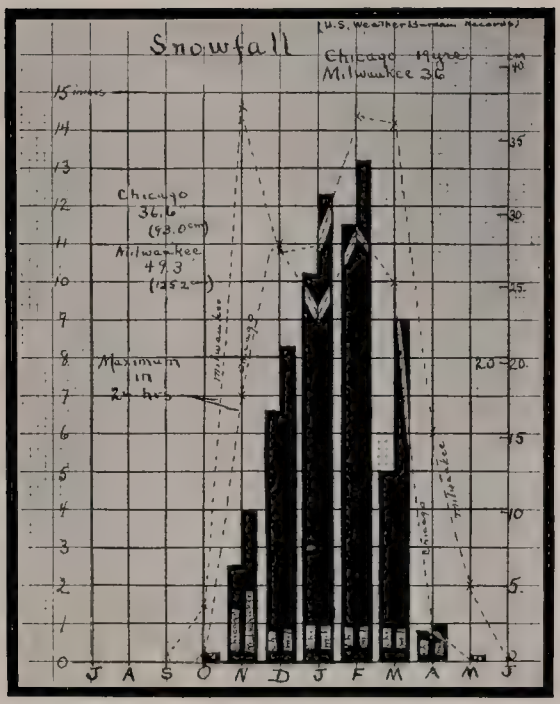
Wind direction; sunshine and temperature curves for Chicago and Milwaukee.

Plate XLI.

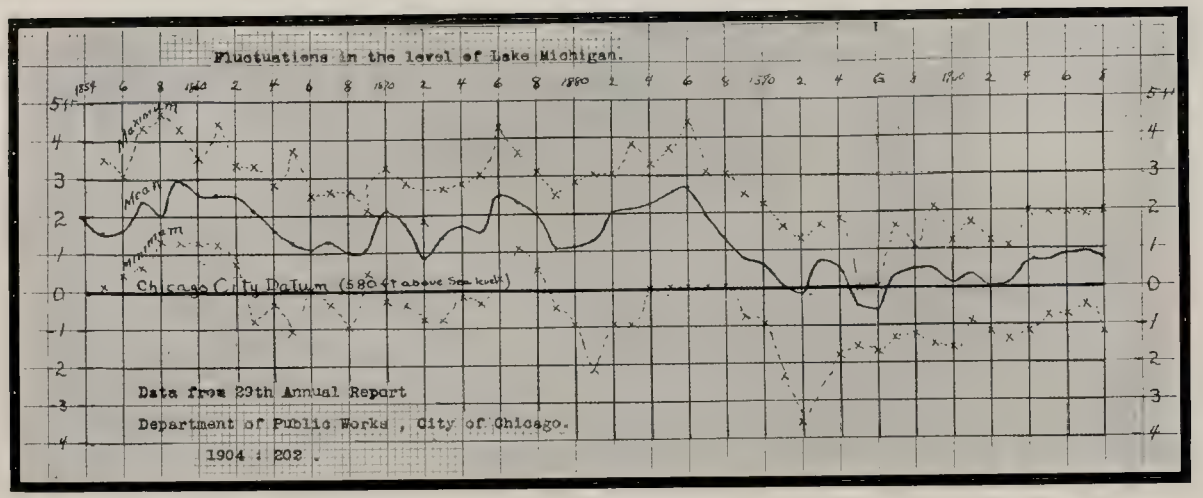


Mean precipitation for Chicago and Milwaukee, by months, for thirty-six years.

PLATE XLII.



Mean snowfall, by months, for Chicago (19 years) and Milwaukee (36 years).



Fluctuations in the level of Lake Michigan from 1854 to 1908.

PLATE XLIII.

Fig. 1. An oak ridge near Kenosha, Wis., which is being washed away by Lake Michigan. November 23, 1909.

Fig. 2. Beach pool near Waukegan, Illinois, showing sanderlings feeding. August 17, 1909.

Plate XLV.

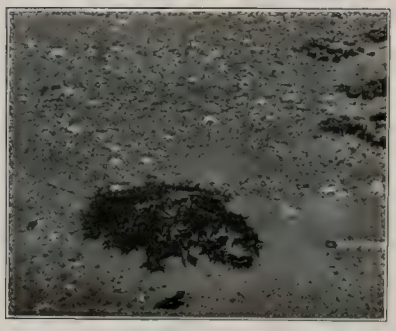


Fig. 1. Little dunes formed by seaside spurge (*Euphorbia polygonifolia*). Beach, Illinois. August 30, 1909.

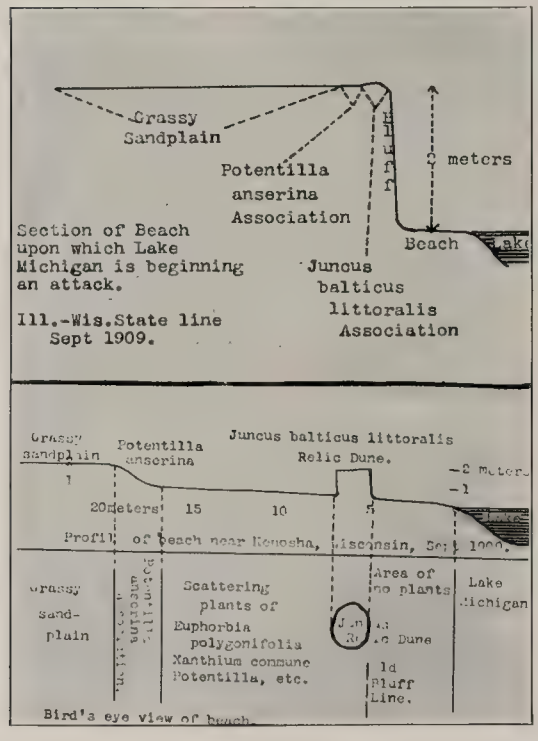


Fig. 2. Diagrams illustrating the character of the shore south of Kenosha, Wisconsin. September, 1909.

Fig. 1 Relic dunes along the shore of Lake Michigan near Kenosha, Wisconsin. A closer view of "A" is shown in Fig. 2. "C" is a nearly extinct relic dune, and "D" is a *Juniperus* relic dune. With the exception of "D" the relic dunes shown are formed by *Juncus balticus littoralis*. August 30, 1909.

Fig. 2. *Juncus balticus littoralis* relic dune, near Kenosha, Wisconsin. November 23, 1909.

Fig. 1. A relic dune near Kenosha, Wisconsin, showing the disruptive power of freezing water. November 23, 1909.

Fig. 2. *Calamovilfa longifolia* dune at Beach, Illinois. July 19, 1909.

Fig. 1. Bluff at Camp Logan, Illinois, being cut by Lake Michigan, showing exposed roots of *Calamovilfa longifolia* on the left, and of red-osier dogwood (*Cornus stolonifera*) on the right. September 4, 1909.

Fig. 2. Part of the beach near Beach, Illinois, showing an *Ammophila* dune in the foreground, a *Salix glaucophylla* dune on the right, and, in the center of the background, a *Populus candicans* dune. September 11, 1909.

Fig. 1. Section of a *Juniperus horizontalis* dune, Beach, Illinois. July 19, 1909.

Fig. 2. A willow (*Salix glaucophylla*) dune, 0.7 meter high, near Kenosha, Wisconsin. November 23, 1909.

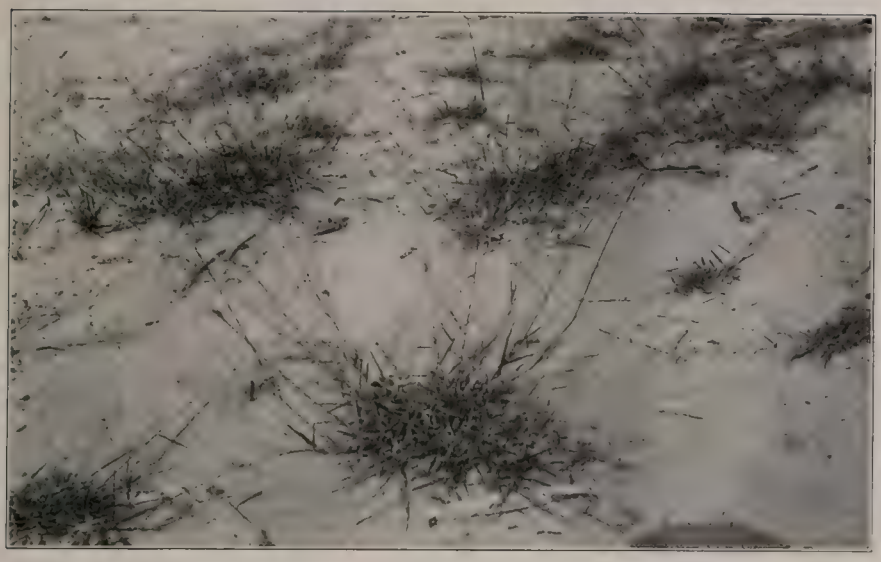


Fig. 1. *Sporobolus cryptandrus*, illustrating growth habit. Winthrop Harbor, Illinois. August 30, 1909.

Fig. 2. *Andropogon scoparius* bunch-grass prairie near Beach, Illinois. August 17, 1909.

Fig. 1. Growth habit of *Petalostemum purpureum* f. *arenarium* in the bunch-grass prairie, Waukegan, Illinois. August 13, 1910.

Fig. 2. Blowout in the oak (*Quercus velutina*) association near Beach, Illinois. Revegetation consists largely of heath plants, but scattered throughout are oak seedlings. July 19, 1909.

Fig. 1. Heath near Beach, Illinois. *Juniperus horizontalis* in the foreground. Back of a strip of sand is bearberry (*Arctostaphylos uva-ursi*) In the background is a tree of white pine (*Pinus strobus*) and a grove of black oak (*Quercus velutina*). August 24, 1909.

Fig. 2. Blowout in the heath, Zion City, Illinois. Revegetation mainly by heath plants. September 4, 1909.

Fig. 1. Blowout on the edge of the oak (*Quercus velutina*) near Beach, Illinois. Revegetation by prairie, marsh, and thicket plants. September 11, 1909.

Fig. 2. Marsh associations in the Dead River near Beach, Illinois. Yellow water-lily (*Nymphaea advena*), arrowleaf (*Sagittaria latifolia*), cattail (*Typha latifolia*), and reed (*Phragmites communis*). August 13, 1910.

Fig. 1. *Scirpus americanus* (3-angled bulrush) association toward the left hand side. *Scirpus validus* (giant bulrush) association at the right of the center. Beach, Illinois. August 24, 1909.

Fig. 2. Swale south of Beach, Illinois, dominated by *Cladium mariscoides*. Pines in the background. September 11, 1909.

Fig. 1. A swale near Zion City, Illinois, showing the *Calamagrostis canadensis* association in the foreground and an aspen-willow grove in the background, separated by a narrow zone of shrubs. September 4, 1909.

Fig. 2. *Phlox glaberrima* consocies of the blazing star (*Liatris spicata*) prairie. Beach, Illinois. July 19, 1909.

Plate LVI.

Fig. 1. Blazing star (*Liatris spicata*) prairie, Zion City, Illinois Balm of Gilead (*Populus candicans*) in the background. September 4, 1909.

Fig. 2. The prairie invading the pines. One of the last stages, showing old trees scarcely alive while no seedlings are present. Beach, Illinois. June 22, 1909.

BULLETIN

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OF

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URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. JANUARY, 1913 ARTICLE VI.

THE MIDSUMMER BIRD LIFE OF ILLINOIS: A STATISTICAL STUDY

BY

STEPHEN A. FORBES

ARTICLE VI.—*The Midsummer Bird Life of Illinois: A Statistical Study.** By STEPHEN A. FORBES.

In the course of a statistical survey of the bird population of the State of Illinois, begun with a view to a better knowledge of the significance of birds in the economy of nature, two field observers, A. O. Gross and H. A. Ray, engaged in this work as assistants on the State Natural History Survey, spent virtually a month of the summer period of 1907 in each of the three principal sections of the state—June in southern, July in central, and August in northern, Illinois. Selecting in each section a locality typical for that part of the state, they made regular trips on foot in various directions and to various distances, traveling always thirty yards apart, and noting as they went the species and numbers of all birds flushed by them on a strip fifty yards in width, including likewise those flying across this strip within a hundred yards to their front. They kept record, also, by means of mechanical counters, of the distances traveled over each distinguishable kind of area, commonly marked by the crop which is borne.

The present paper is a report of a few of the more general results of a study of the materials thus brought together, illustrating the numbers and ecological distribution of the birds of Illinois during the relatively stable period of their summer residence—the time between the conclusion of the spring migration and the beginning of the fall movement to the southward. It is a period of breeding and steady habitation for our most permanent and characteristic bird population, and will best help us to an understanding of the main normal ecological significance of Illinois birds.

THE AREA OF OBSERVATION

The total distance traveled by my observers on these various midsummer trips was 428 miles (omitting fractions), of which 141 miles was in southern Illinois, 112 in central, and 175 in northern. The total area covered by this strict census of the bird population was a trifle over 12 square miles, or 7,693.5 acres—33 per cent. of this acreage being in the southern, 26 per cent. in the central, and 41 per cent. in the northern, part of the state—or approximately a

*Reprinted from the American Naturalist, Vol. XLII, August, 1908.

third of this area in southern, a fourth in central, and two fifths in northern, Illinois. The field observations began in the south June 4, and ended at the north August 23, with the idea of avoiding, so far as possible, by this order of progress, differences due to different seasonal conditions. It was not possible, of course, to eliminate these wholly, with only one pair of observers; and it will tax our ingenuity, and sometimes perhaps oxertax it, to detect these differences and to distinguish them from those due to mere difference of latitude and of climate corresponding.

The total surface on which these precise midsummer observations were made was 1/4720 part of the whole state, and the question at once arises, Was this area sufficient to give these results any general value for the state at large, and, if so, how may we be sure of it? There is, I believe, no mathematical method of determining the sufficiency of these data for generalization purposes, and I know of no test at present applicable except that of the general consistency and reasonableness of the totals, averages, and ratios, for the different districts and seasons, the presence or absence of which each can readily see for himself as this discussion proceeds. If the data of observation are insufficient for the uses made of them, there will be a random variability and inexplicable irregularity in my statistical summaries which we shall not fail to notice.

General Product of the Survey

Gross and Ray identified during the summer, on the territory covered by their data, 7,740 birds, belonging to 85 species. This is at the rate of 645 birds per square mile, or almost precisely 1 per acre, including the so-called English sparrow. If we omit the 1,414 interloping English sparrows observed—which is a little more than 18 per cent. of the entire number of birds—we have remaining 527 *native* birds to the square mile. The total for Illinois,* on this basis, is 30,750,000 native birds and 5,536,000 English sparrows, or approximately 14 summer resident birds to each person in this state living in the country or in towns of less than 25,000 inhabitants.

Of the 85 species represented by the 7,740 birds recognized on these trips, the 21 most abundant species were represented by 6,596 birds. That is to say, 85 per cent. of the birds belonged to 25 per cent of the species. The 21 more abundant species numbered, taken

*A combination of the averages for the three sections of the state, computed separately, the data for the sections being differently weighted to compensate for differences in area.

together, 550 to the square mile, and the 64 less abundant species, taken together, numbered 95 birds to the square mile, or 1 to every 6¾ acres. The latter species are evidently negligible as general factors in the ecological system, and attention need be given, in discussing the birds of the state as a whole, only to the 21 species common enough to produce some appreciable general effect. Given in the order of their abundance they are as follows.

A. O. U. Nos.	Bird	No. observed	Per cent.
X	English sparrow	1,414	18.4
501	Meadow-lark	1,025	13.2
511b	Bronzed grackle	900	11.6
316	Mourning-dove	461	6.
604	Dickcissel	393	5.1
498	Red-winged blackbird	347	4.4
474b	Prairie horned lark	296	3.8
412	Flicker	197	2.6
761	Robin	194	2.5
563	Field-sparrow	186	2.4
529	American goldfinch	158	2.
444	Kingbird	126	1.8
494	Bobolink	119	1.5
546	Grasshopper sparrow	110	1.4
705	Brown thrasher	104	1.3
495	Cowbird	102	1.3
406	Red-headed woodpecker	99	1.3
613	Barn swallow	96	1.2
289	Quail	91	1.2
261	Bartramian sandpiper	89	1.1
488	Crow	89	1.1
		6,596	85.2

Variation with Latitude

The English sparrow decreases in abundance from north to south, from 147 to the square mile in northern to 113 in central, and 82 in southern, Illinois. One hundred sparrows in the northern part of the state are thus represented by 77 in the central and 56 in the southern part.* The *native* summer residents, on the other hand, increase in numbers from north to south, the birds per square mile being 464, 537, and 600 for northern, central, and southern Illinois, respectively. That is, 100 native birds in northern Illinois were represented in midsummer by 116 in central and 129 in southern Illinois. The decrease in English sparrows from north to south is

*Since the above was written, my attention has been called, by Dr. Hans Gadow, to the fact that in Europe also this sparrow diminishes in number southward.

not sufficient to offset the increase in the native species, the total numbers per square mile for all summer birds in the three sections of the state being 610, 650, and 682—or 100 birds in northern for 107 in central and 112 in southern Illinois.

This same gradation was much more pronounced in the record of the *winter residents*. From the last of November to March 15, birds averaged 384 to the square mile in northern Illinois; from December 23 to March 21, 582 to the mile in central Illinois; and from February 6 to February 21, 832 to the mile in southern Illinois,—numbers related to each other as 100, 151, and 217. Indeed, we find birds more abundant in extreme southern Illinois in the midwinter period of 1906-07 than in the midsummer period of 1907, averaging at the rate of 122 birds in the former season to each hundred in the latter.

If we take into account the numbers for the whole year, there are for every hundred birds in the northern part of the state, 133 for central and 181 for southern Illinois.

Birds by Sections

	Northern Illinois	Central Illinois	Southern Illinois
Summer:			
Native	100	116	129
Sparrows	100	77	56
All birds	100	107	112
Winter:			
Native	100	170	292
Sparrows	100	65	1
All birds	100	151	217
Whole year:			
All birds	100	133	181

The bobolink was a distinctly northern bird, occurring in the ratio of 24 to the square mile in northern Illinois, and not at all in either of the other sections. The mocking-bird, on the other hand, was almost exclusively southern, being represented by 8 birds to the square mile in the southern section, by only 1 specimen seen in central Illinois, and not at all in the northern part of the state.

Migration Waves

In a paper published in April, 1907, under the title "An Ornithological Cross-section of Illinois in Autumn,"* I gave the data and re-

*Bull. Ill. State Lab. Nat. Hist., Vol. VII, Art. 9.

sults of a trip across central Illinois made by Gross and Ray during the fall of 1906. A comparison of the general average of the bird population, determined from the data of this trip for the period of the fall migrations, with the midsummer average for the same section of the state, as determined July, 1907, shows an interesting difference which leads us to consider the effect of the autumnal movement to the south on the numbers of the local bird population. On the above trip across the state, made between August 28 and October 17, 1906, a general average of 579 native birds to the square mile was found, while the corresponding midsummer average for the year 1907, is 537 native birds to the square mile—a difference of 42 birds to the mile, or nearly 8 per cent, in favor of the fall population.

Native Birds per Square Mile, Fall (1906), Summer (1907)

	Migrant	Resident	Total
Summer		537	537
Fall	98	481	579
Difference	+98	—56	+42

Was this difference due to the fact that the fall migration was in progress when the observations for 1906 were made? That is, does the migration movement begin first at the north and result in a local wave of increased numbers, birds coming in from the north earlier and faster than the resident species leave for the south? It is possible to answer this question by reference to the data of the paper just cited.

An analysis of the list of species identified on the autumnal trip of 1906, shows that 481 per square mile of these birds were summer residents, still remaining, and that 98 per square mile belonged to migrant species, on their way to the south. The summer residents still present in this autumnal period were thus 56 per square mile fewer than the resident birds of the summer of 1907. That is, 56 summer residents for each square mile of central Illinois had gone south, on an average, and 98 fall migrants had, on the other hand, come in to take their place, the difference between these numbers giving us the excess of 42 birds per square mile of fall over summer. This temporary increase of 8 per cent. in autumn in the average number of our birds is thus evidence of a wave of condensation running southward in consequence of the earlier beginning

and more rapid development at the north of the annual fall migration.

This contrast of the number of the resident summer population with that of the fall migration period is still more clearly and strongly shown by a comparison of the totals of all our central Illinois observations in midsummer and in fall, respectively. These average 1.07 birds to the acre for the period from July 9 to September 21, and 2.31 per acre for the interval between the 1st and the 26th of October. That is, more than twice as many birds per acre were seen in October, 1907, as in July, August, and September.

The data of the *spring* migration of 1907 are unsatisfactory owing to the extraordinary character of the season, and the consequent repeated interruption and remarkable prolongation of the movement. Nevertheless, they indicate a larger population during the early part, at least, of this migration period also than either before or after it. A trip down the eastern side of the state from Cook to White county, begun March 26 and ending April 11, gave an average of 1.34 birds to the acre—a number to be compared with our midsummer average for the whole state, which is 1.03. That is, the average early spring population of this exceptional year was 30 per cent. greater than the average of the summer following. On the other hand, a trip across central Illinois between April 20 and May 29, still within the migration period, gave us, for 5⅓ square miles of area, an average of only .89 per acre—less than even the midwinter average of .91 for the same part of the state.

Vegetation of the Inspection Area

As a basis for a more precise account of the distribution of birds as a whole and of the more important species, it will be necessary to consider the vegetable covering of the soil, since there is little else in Illinois by which different portions of its area may be distinguished. The territory traversed by my observers, it need hardly be said, was almost wholly under cultivation. Excluding only forests in which the trees were too high, or the undergrowth was too dense, to permit a full and accurate census of the birds, the territory reported upon was chosen wholly at random, and the total for each division of the state seems sufficient to give us, with the exception just mentioned, a fair sample of its crops and surface conditions. The areas from which all the birds were determined were 3,172 acres for northern Illinois, 2,117 acres for central, and 2,504 acres for southern.

In the upper third of the state, 95 per cent. of the surface was in corn, small grain, and grass—31 per cent. in corn, 27 per cent. in small grain (nearly all of it oats), and 37 per cent. in the pasture and meadow crops, about equally in each. In the central region the area in corn rises to 46 per cent. of the whole, that in small grains was about 26 per cent. (again nearly all oats), and that in the forage crops was 27 per cent. (the pasture lands nearly twice as extensive as the meadows)—a total of 99 per cent. of the area examined which was devoted to these great farm crops. In the lower third of Illinois only 23 per cent. of the land was in corn, an almost equal area (21 per cent.) was in small grain—more than half of it wheat—and 44 per cent. was in grass, clover, and similar forage plants, rather equally divided between pastures and meadows. That is to say, the areas in corn and small grains were nearly the same, and these together were barely equal to the meadows and pastures. The total

Crop Areas. Per cent., 1907

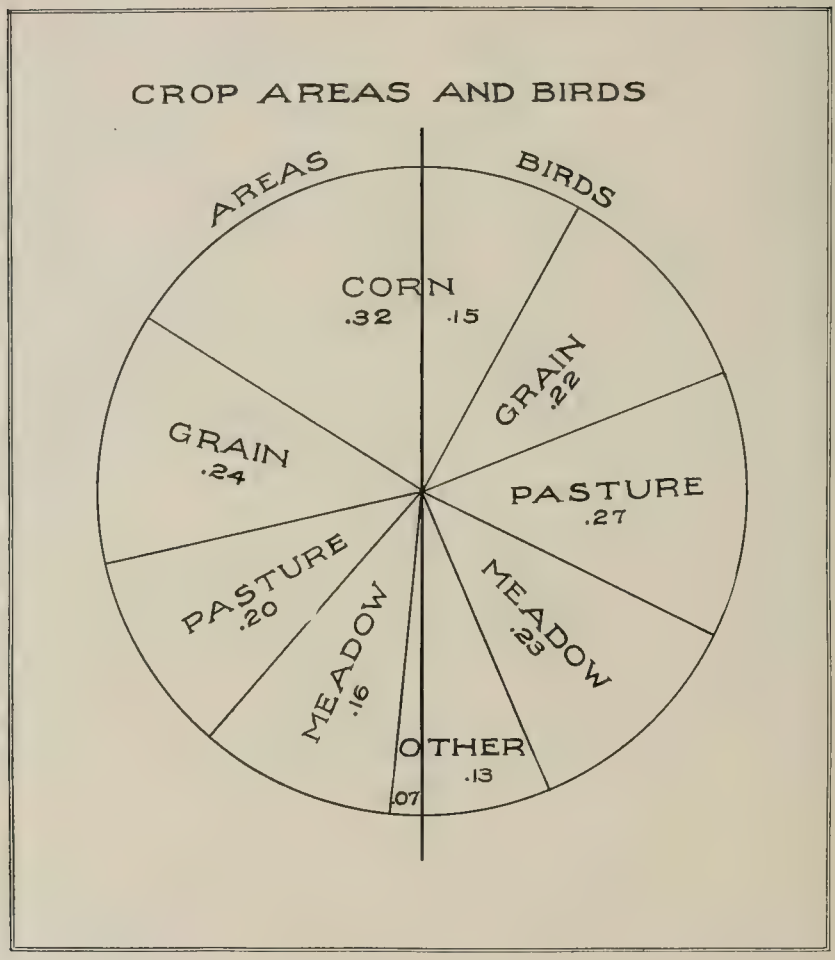
	Northern Illinois	Central Illinois	Southern Illinois
Corn	31	46	23
Grain	27	26	21
Grass	37	27	44
Miscellaneous	5	1	12

in all these crops was 88 per cent. of the area inspected, the remaining 12 per cent. covering the orchards, the more open woods, the waste and untilled lands, and a few additional minor items.

Numbers of Birds by Crops

Illinois is still a prairie state in the predominance of birds which prefer a grassy turf as an abiding place. Almost exactly half of those recorded for the state in the summer of 1907 were from pastures and meadows, although the total acreage in these lands was but 36 per cent. of the entire area inspected. These figures are equivalent to a density ratio on pastures and meadows of 1.39 for all the birds of the state.* Corn is an exotic crop in Illinois, and birds were only about a third as abundant in corn fields as in grass lands, while in small grains they were nearly twice as abundant as in corn. The acreage in these crops was such that 15 per cent. of all the birds of the season were found in corn fields and 22 per cent. were in small

*That is, taking an average density of the bird population for the whole area of the state as 1, the density in pastures and meadows only is 1.39.



grain. In orchards they averaged 4½ times as numerous to the unit of area as in fields of grain, 2,471 to the square mile—giving a density ratio of 3.84; but the acreage in orchards from which the birds were identified was so small that all the orchard birds together amount to only 2 per cent. of the whole number observed. Among native trees and shrubbery, birds were much less abundant than among fruit trees, and the density ratio for these situations was about 2.25.

By way of further illustration of the application of this quantitative method to the subject of local distribution, I will present some

of the more pronounced results for one species of bird throughout its range in summer, and for one kind of crop area as visited or inhabited by midsummer birds.

The Meadow-lark

One thousand and twenty-five meadow-larks were identified by my observers in their work on the summer residents of the state, an average of 85 to the square mile for the whole area traversed by them. As these birds were unequally distributed, never occurring, for example, in woodlands or among shrubbery, their numbers rose in some situations far above this general average, amounting to 266 to the square mile in stubble, 205 in meadows, 160 on untilled lands, 143.5 in pastures, and 131 on waste lands, and falling to 10 to the square mile in fields of corn.

Meadow-larks per Square Mile. Summer, 1907

Stubble	266
Meadows	205
Fallow	160
Pastures	143.5
Waste	131
Corn	10
Woods	—
Shrubs	—
State	85

They varied also in abundance, in a very interesting way, from the north to the south. One hundred of them in northern Illinois were represented by 175 in central and by 215 in southern Illinois. This variation was evidently independent of any difference in the extent of surface covered by the kinds of vegetation which they most prefer, since the, ratio of pasture, meadow, waste and untilled lands taken together was considerably less for central than for northern Illinois, although the meadow-larks were 75 per cent. more numerous; and it was only a fourth greater for southern Illinois than for northern, although the meadow-larks were more than twice as abundant. The cause of the greater numbers southward, so far as I can see, can be accounted for only rather vaguely as climatic.

Much more difficult of even general or hypothetical explanation is a curious difference in the observed abundance of meadow-larks in pastures and meadows respectively, in the three divisions of the state. In northern Illinois there were 87 larks per square mile in pastures to 129 in meadows; in southern Illinois there were 125 in

pastures to 297 in meadows; while in central Illinois this relation was reversed, the number in pastures being 274 to the mile, and that in meadows 189. That is, while 100 pasture birds were represented in northern Illinois by 148 in meadows, and in southern Illinois by 242, in central Illinois they were represented by only 69. Since the southern Illinois observations were made in June, those for central Illinois in July, and those for northern Illinois in August, one naturally looks to differences in season, in the advancement of the crops, or in agricultural operations as related to the haunts and habits of these birds, for an explanation of their apparent shift from meadows to pastures in July in central Illinois, and a seemingly plausible explanation is suggested by the fact that haying was mainly done during July in the central part of the state, but was not yet fairly begun in southern Illinois in June and was nearly over in northern Illinois in August.

Pasture Birds per Square Mile. Summer, 1907

Meadow-larks

	Northern Illinois	Central Illinois	Southern Illinois
Pasture	87	274	125
Meadow	129	189	297
Other Pasture Birds			
Pasture	50	54	120
Meadow	200	131	371

If, however, the meadow-larks were disturbed to this extent by the operations of making and saving the hay crop, one would expect to find the other distinctively meadow birds similarly affected—a supposition which is not borne out by the facts of our record. Besides the meadow-larks, there were five common species more abundant in meadows in one or another section of the state than in any other important situations; namely, the red-winged blackbird, the purple grackle, the vesper-sparrow, the grasshopper sparrow, and the dickcissel. Each of these species was, moreover, more abundant in meadows than in pastures in each section of the state—in central Illinois as well as in the other two—excepting only the grackle in southern Illinois. Taking all five of these birds together, there were in northern Illinois 200 to the square mile in meadows and 50 in pastures, in central Illinois 131 and 54, respectively, and in southern Illinois 371 and 120. In other words, for each hundred of these

five kinds of birds in meadows, there were, in the northern section, 25 of them in pastures, in the central section 41, and in the southern section 32. The cause of this apparent change in the preference of the meadow-larks of central Illinois seems, therefore, something peculiar to themselves, and is still to seek.

Birds of the Pastures

The birds of a given situation may be discussed from two quite different standpoints, both interesting and pertinent, and both really necessary to a complete understanding of the facts. We may consider the members of an assemblage of species there with first reference to their relative importance to the situation itself—with reference, that is, to their comparative numbers, or to the nature and effect of their activities; or we may consider the situation with first reference to its relative importance in the economy and life of each species of bird which inhabits or visits it. If this situation is woodland, for example, a bird found only in forests might, if a comparatively rare species, have very little importance—might produce very little effect in the situation because of its infrequent occurrence there, while to the species itself the forest situation would be all-important, as the sole place of its habitation. Its own significance in forests might be easily overbalanced by a very abundant species which should visit woodlands only occasionally, but whose average numbers there might be twice or thrice as large to the unit of area and time as those of the less abundant species inhabiting forests exclusively. Time will not permit me to illustrate this division of my topic from both these points of view, and I will limit myself to a few words in conclusion on the *pasture birds* as a group and on some of the more prominent pasture species with reference to their importance in pastures.

Pasture lands were the preferred resort of our most abundant midsummer birds. That is, more birds were seen in pastures than in any other of the larger crop areas of the state—2,107 in that situation as against 1,814 in meadows, 1,752 in fields of small grain, and 1,169 in fields of corn. Indeed, 27.2 per cent. of all the midsummer birds determined by my observers were seen in pastures, 23.4 per cent. in meadows, 22.6 per cent. in small grain, and 15.1 per cent. in corn. The area in pastures was larger than that in meadows, however, and on this account, if we consider the number of birds per square mile, we must change this order of precedence. With a general midsummer average of 645 birds to the square mile

for the whole state, we have 920 to the mile for meadows, 878 for pastures, 562 for small grain, and 300 for corn. Or, if we take the number per square mile for the entire state as 1, 1.36 will be the density ratio for pastures, 1.43 for meadows, .87 for grain fields, and .47 for corn fields.

Summer Birds in Crops, 1907.

	Numbers	Ratio	Per square mile	Densities
Pastures	2,107	27.2	878	1.36
Meadows	1,814	23.4	920	1.43
Grain	1,752	22.6	562	.87
Corn	1,169	15.1	300	.47
Other	898	11.6		

Looking to the composition in species of this midsummer pasture population, we find that more than half the summer resident birds of Illinois pastures belong to five species—the English sparrow, the meadow-lark, the crow-blackbird, the horned lark, and the field-sparrow, relatively abundant in the order named; and this statement is almost as true of the three sections of the state as it is of the state as a whole. Comprising nearly 53 per cent. of the pasture birds of the entire state, these five species made 49 per cent. of those of northern Illinois, 61 per cent. of those of central Illinois, and 47.5 per cent. of those of southern Illinois. Indeed, the first four of these species were the most abundant pasture birds of the whole state for the whole year, occurring there in the following numbers: English sparrows, 1,394; crow-blackbird, 696; meadow-lark, 686; horned lark, 603; and field-sparrow, 230. These are consequently our most typical pasture birds. In the pastures of the state at large the English sparrow was the most abundant species, making 20 per cent. of all the birds seen in pastures during the summer months, and the meadow-lark was nearly as common, making 17 per cent. of these birds. The meadow-lark was, indeed, the *most* abundant pasture bird in both southern and central Illinois, the sparrow surpassing it only in the northern division of the state. The horned lark, on the other hand, was second in northern Illinois, but tenth in both central and southern Illinois, and fourth for the state as a whole. The crow-blackbird was third on the list for the whole state, fourth for southern Illinois, third for central, and sixth for northern Illinois.

Ten species comprised more than two thirds of the pasture birds of the state, and these same ten species made 63 per cent. of the

birds of northern Illinois pastures, 80 per cent. of those of central Illinois, and 64 per cent. of those of southern Illinois. Besides the five species already mentioned, these were the flicker, the robin, the mourning-dove, the red-headed woodpecker, and the red-winged blackbird.

One general impression made by this preliminary examination of the present bird population of the State of Illinois is that of a remarkable flexibility and tenacity of the associate and ecological relationships of birds in the face of revolutionary changes in their environment. Apart from the results of the introduction of the English sparrow, and the direct destruction of game birds and birds of prey, the main effect of human occupation seems to have been the withdrawal of most of the prairie birds from the area devoted to Indian corn, and their concentration in pastures, meadows, and fields of small grain—situations which most nearly resemble their original habitat.

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STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

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ART. VII. OBSERVATIONS ON THE BREEDING OF THE EUROPEAN CARP IN THE VICINITY OF HAVANA, ILLINOIS.

ART. VIII. OBSERVATIONS ON THE BREEDING HABITS OF FISHES AT HAVANA, ILLINOIS, 1910 AND 1911.

BY

R. E. RICHARDSON, A.M.

ARTICLE VII.—*Observations on the Breeding of the European Carp in the Vicinity of Havana, Illinois.* BY R. E. RICHARDSON.

Observations on the breeding habits of the European carp were begun at the opening of the Illinois Biological Station in late April, 1910, and carried on throughout the remainder of the spawning season; while the search for fry and fingerlings, with the object of ascertaining their habits, habitat, local preferences, etc., was continued until the Station closed in September. In the season of 1911 similar observations were in progress, practically continuously, from April 15 to June 8.

LOCALITIES

The localities within five miles of Havana that have been most frequented by carp for spawning since 1900, are chiefly the shallow overflowed fields and marshes along the Thompson's Lake bottom between Flag Lake and the west bluff and the region about the mouth of Spoon River. All of the places described in the list following are within this radius except the last two.

1. *Danhole's Field.*—This is a 600-acre tract, formerly a cultivated field, lying between the south end of Thompson's Lake and the west bluff, and immediately north of Lynch Slough. Except for two small "guts" at the south end, leading into Lynch Slough, a lotus pond of about one acre in the middle of the east side of the field, and a few narrow ridges toward the north end, the contour of the bottom of this marsh does not show great variation. The entire field is normally overflowed in April and May to a depth of one to three feet. Over almost the entire field is scattered a more or less dense growth of "flag" (*Scirpus fluviatilis*), while beneath and between the flags, and entirely covered by water through April and May, is usually to be found a carpet of short bog-rush (*Juncus*). With less uniformity of distribution but in places covering several acres continuously, are to be seen thick beds of smartweed, and mere scattering patches of cut-grass (*Leersia*), arrowhead (*Sagittaria*), and pickerel weed (*Pontederia*).

2. *Spoon River "Horseshoes" and adjacent Flats.*—Here are included several hundred acres of overflowed flats, largely timbered, lying between Spoon River and Deep and Lynch sloughs, and between the C., B. & Q. R. R. and the Illinois River. In summer these flats

are, as a rule, dried up to a considerable extent, or completely so except for the "horseshoe ponds," which are remnants of an old bed of Spoon River.

3. *Beck's Swale and connecting Ponds.*—This small swale and connecting marsh-land parallels the river in a narrow strip for most of the distance between the Isabelle Township ditch and the C., B. & Q. R. R. Station at West Havana. The ponds on Beck's land, just south of the old Illinois Central bridge, are all small, the largest not over 100 ft.×30 ft. They are connected with the township ditch by the swale at high water.

4. *Schulte's Field and neighboring Marshes.*—An overflowed field of about 50 acres, owned by J. C. Schulte, lying between the Isabelle Township ditch and the C., B. & Q. tracks, about half a mile west of the river. This area was cultivated previous to 1900, and even now crops of grass are taken from it in late summers of moderately dry years. In April and May the water is one to two feet deep over the field. Similar land in the immediate vicinity brings the total acreage available here as spawning grounds in normal seasons up to approximately 200 acres.

Many of these marshes are newly made—the result of rise in river levels due to drainage canal water—these bottoms having been cultivated fields previous to 1900. They are now overflowed throughout the spring season and usually till the first or middle of June to a depth of six inches to three feet or more. During this period there are usually large variations in water levels in the marshes; and towards the close of the spring freshet season, there are likely to be rather wide and sometimes sudden fluctuations in water levels and temperatures.

5. *Head of Flag Lake, northwest Shore.*—One hundred acres or more of "flag", smartweed, and willows. Bottom generally rather sandy; depth of water, 1 to 3 feet, April and May, 1910 and 1911.

6. *West Shore of Thompson's Lake, Warner's Cut to Big Cove.*—A narrow strip, several hundred acres in extent, of shallow water, 1 to 3 feet deep. Smartweed, pondweed, willows, and button-bush; the bottom mostly soft black mud, but in places there is considerable sand.

7. *Dierker Lake.*—A small lake, about half a mile long, just below Matanzas Lake. Smartweed and willows along shores; mud bottom, little sand.

8. *Sangamon Lake.*—At the south end of this lake or "bay", which is six miles north of Beardstown, are extensive mud flats, several hundred acres in extent, covered with willows, cut-grass, smartweed, and pondweed (*Potamogeton*); also considerable hornwort (*Ceratophyllum*). Depth of water, May, 1911, 1 to 3 feet.

Equipment

The equipment used in making the field observations was extremely simple, and for the most part was as follows:

1. A flat-bottom skiff of light draught, with wide stern.

2. A black calico-covered sun-hood, so constructed that it could be easily set up, clamped, and disconnected from the stern of the skiff.

3. A small, hand water-glass, for close observation of the bottom. This glass, cemented into the end of a 40-inch tube, 6×6 inches in section, could be lowered to or very near bottom in as much as three feet of water.

4. A garden rake for lifting bog rush, smartweed, sodden drift, etc., on which eggs were seen, by use of the sun-hood or water-glass, to have been deposited.

5. The ordinary field collecting utensils employed in collecting and preserving zoological material.

We had also as field helper, at the oars and in every service in which help was needed, an experienced, intelligent, and interested fisherman and mechanic*, to whom is due no small part of the credit for whatever success attended the season's operations.

Journal of Field Observations, 1910-1911

nineteen hundred and ten

March. Although the month of March was exceptionally dry and warm throughout, no reports of spawning of carp came in from fishermen. The Illinois River gage stood at 14.1 ft. March 15, and fell gradually to 12.9 ft. by the end of the month. Between March 18 and April 1 the surface temperature of the water in the channel of the river, at our regular plankton station, rose from 44° to 60° Fahr., and in Thompson's Lake, at the regular plankton station, it rose from 40° to 60°. The plankton (silk-net catches) in Thompson's Lake was nearly quadrupled in the week between March 18 and 25, and by April 1 had increased to nearly nineteen times the amount present on March 18.

April. During the first half of April moderate weather prevailed, water temperatures in the river and Thompson's Lake remaining between 60° and 64° Fahr. The river gage declined gradually through the month, from 12.8 ft. to 10.2 ft. Between April 8 and 20, large numbers of carp were reported to have been heard and seen "splash-

*Henry C. Allen, of Havana.

ing"* at various points in the vicinity of Havana. If any judgment is possible from a comparison of the frequency of these reports with those that came in later, it seems probable that the majority of the carp at Havana spawned between April 10 and 25. A cold spell between April 20 and 25 resulted in a drop of water temperature to 46° by April 25. No reports of spawning activity were received between this date and the beginning of the second week in May. The warmer days, preferably when a light south wind is blowing, seem usually to be chosen by the carp for spawning.

May. The first week in May was cool and rainy, and no spawning movement was reported. The weather cleared and moderated after May 7. The surface temperature of the water in Thompson's Lake rose from 46° to 62° Fahr. between April 25 and May 2, and increased gradually thereafter, the maximum air temperature reaching 72° on May 9. Numerous reports of spawning activity of carp came in between May 7 and 9, and on the last-named date the greater part of the day was spent by Allen and myself in making observations on the breeding grounds in Danhole's field.

May 9. Went with Allen and outfit to Danhole's field morning and afternoon. Carp splashing in south end of field all day—two or three or half a dozen in one place. Giggers (farmers), with pitchforks, wading about. In the part of the field in which carp are now spawning the water is from 1 to 3 ft. deep. The bottom is for the most part thickly covered with a fine short bog-rush, cut-grass, and smartweed. At the surface a good deal of loose drift—dead twigs, etc.—is floating. Examination of the bottom with the water-glass shows eggs in large numbers attached to the submerged vegetation and drift—green bog-rush and grass and dead grass and brush. Most of the eggs are in water 2 ft. or more in depth, and in such places as are most densely covered by floating drift. They are clearly seen with the water-glass in two feet of water, and easily lifted to the surface, with the bog rush and drift to which they are attached, by the use of a common garden rake. The floating trash is also very generally sprinkled with eggs, doubtless thrown out of the water into the air by the carp as they crowded and turned or were thrust on their sides in the act of spawning. Large numbers of eggs are fungused, indicating that they have been spawned some days, but presumably during the first week of May. Several hundreds of eggs were taken into the laboratory and put into aquaria for observation.

In the south hundred acres of the field, counts were made in vari-

*"Splashing," "rolling," "fluttering," etc., are terms used by fishermen to describe movements of carp in the act of spawning.

ous places of the number of eggs over a square yard or less of bottom. These counts varied from a minimum of 100 to a maximum of 2500 per square yard. It was difficult to find anywhere an area of bottom, however small, within the entire southern third of the field—the only part examined—on which at least some eggs had not been deposited. If we assume that the field has, as reported, an area of 600 acres (2,903,617 square yards), and that the eggs are distributed over the whole area at the same rate as in the south third*, that is, at the rate of 500 per square yard, which is probably a conservative estimate considering the very high density of distribution in those portions where most splashing has been done, we have for the field a total of 1,451,818,500 eggs. At the average rate of 500,000 eggs apiece (the number estimated by Cole and others for 5- to 6- lb. carp), it would take 2903 females of five to six pounds' weight to furnish these eggs. This is equivalent to saying that at various times and places in the field between May 1 and May 9, *29* lots of *100* females each, spawned in the whole field. Looked at in this light our estimate is, indeed, in all probability too low†, and is so considered by the best-informed and most observing fishermen, to whom it is no uncommon experience to see *several hundred* carp splashing at one time in a space of less than an acre.

May 12. Eggs in Danhole's field are advancing rapidly towards hatching (embryo turning inside egg), but the number of fungused eggs has increased greatly since May 9. After making test counts in various places, it was estimated that in the neighborhood of ten per cent. of the eggs have eye-spots, the rest being fungused. This gives a total hatch of 145,181,850 out of the 1,451,818,000 eggs present May 9. In the south end of the field some fresh eggs, spawned in the past three days, were found. Several lots of eggs of various ages again taken to laboratory for observation. A few of these hatched on the way in. These eggs are evidently somewhat further advanced than those from same lot brought in to the laboratory on May 9.

In afternoon, visited Beck's Swale and ponds, between river and C., B. & Q. Station at West Havana. Mr. Beck says that a hundred or more large carp were rolling yesterday (May 11) in the swale behind his house. They come up by way of the township ditch. The

*Note that we got several reports of carp splashing in the upper part of the field, behind the club house, between April 15 and May 15.

†Additions should also probably be made to these numbers to allow for eggs spawned before and after the estimates were made, as these refer only to eggs in field between May 9 and 12, *and not to the total spawned during the whole spring season.*

wind was in the south on May 11. We found large quantities of carp eggs in the swale—on the bottom and on floating drift. About half of them were quite fresh in appearance and showed no fungus; the rest were older and largely fungused. They probably belonged to a lot spawned before or on May 9, about which dates also carp were splashing here, according to Beck and J. C. Schulte.

May 13. The water in Schulte's field is now 12 to 18 inches deep. Many carp eggs were found in grass and leaves, both submerged and floating, chiefly in water about 6 inches deep.

May 13. Eggs brought in from Danhole's field May 9 are beginning to hatch.

May 14. Visited Danhole's field in afternoon. Few carp eggs to be seen. About the last of the eggs on which observations were made May 9 and 12, have hatched or disintegrated. Tried pumping up newly hatched fry from the bottom with a small bilge-pump, with coarse silk-net over spout, but got none.

May 15. The last of the eggs brought into the laboratory from Danhole's field May 9, hatched today. The loss by fungus has amounted to about 70 per cent. The smaller percentage of fungused eggs than the 90 per cent. found in the field is doubtless due to the fact that the fungused eggs were carefully picked out and thrown away every day in the laboratory.

May 18. Carp fry in Danhole's field have been hatched a week. They were easily taken today in large numbers with a small cheesecloth seine. The largest numbers of fry are found in about 2 ft. of water, where the bottom is thickly covered with bog rush and scattering flag and smartweed. No fry can be seen anywhere near the surface. They are probably swimming and feeding near the bottom. The water at all levels, in a depth of only 1 to 2 ft., is swarming with a rich entomostracan plankton.

May 19. Carp eggs brought into laboratory from Danhole's field May 12, are all hatched and doing well. These eggs were probably spawned between May 9 and 12 (see above).

May 24. Took large numbers of carp fry half an inch long in Schulte's field, in the shallower portions, where water was only 6 to 12 inches deep, with weedy or grassy bottom. In the deeper parts of the field—18 inches and over—with open mud bottom and no vegetation but scattering smartweeds, no fry were found. Tests with silk net showed that there was much less plankton over soft mud in this open water, which is apt to be roiled by wind because of shallowness, than in the shallower vegetation-filled portions of the field, where there was instead a very rich entomostracan plankton.

The water has fallen in this field about 6 inches since May 12, and the gage is still on the decline. At this rate it may not be many days till the water in the field will be so low that the fry will be scalded or left high and dry.

Water in Danhole's field 8 to 18 inches deep, and going down at rate of 1 inch a day.

Carp fry ¼ to ½ inch long are abundant, and easily taken with cheese-cloth seine.

June 3. Carp coming into market include a good many females full of eggs, some dressing only half their round weight; but most have evidently spawned.

[*June 3-22.* This interval was taken up by the Rock Island plankton trip and preparations for the opening of the University Summer School.]

June 23. Water has fallen about 1.8 ft. since the first of June. Depth of water 4 to 6 inches in south end of Danhole's field. Temperature of water 85° Fahr. Rushes (*Scirpus*), as high as a man's shoulders, choking up the marsh almost completely except for scattering small open spaces 10 to 30 feet across. In these openings we found small fry, ½ inch to 1 inch long, of bass, bluegill, and crappie, but no carp. Have all the carp gone out of the field? If so, where are they? We searched for them in the deeper water of Lynch Slough, just outside of the field, but could find no trace of them.

June 23-30. Tried repeatedly to get carp fry in waters adjacent to Danhole's field,—Lynch Slough, Crabtree dredge ditch, Thompson's Lake, west shore, between dredge ditch and club house, etc. No trace of them found.

July 1. Visited Beck's ponds. They are now very low and all shut off from connection with the township ditch and the river, some being dried up completely. If dry weather continues a few weeks, all will be dry. In one of the largest ponds, 30×100 ft., just dried up, several hundred dead carp, 1 to 2 inches long, were found.

In small pitlike depressions (cow tracks?) in the bottom of this pond, holding from a quart to a gallon of water, with a temperature of 92° Fahr., we found half a dozen carp, ¾ inch long, well-fed and lively, although all about them were skeletons and decaying bodies of hundreds of others.

July 5. Visited Danhole's field. Most of the field has gone dry except for small areas in the middle of the densest flag patches, where water from 2 to 6 inches is present, and the two lotus ponds, which have 2 to 3 feet of water. We searched high and low for young carp, but found none, alive or dead. In the lotus ponds, found

an abundance of large-mouth black bass (1 inch to 2½ inches), young black bullheads, and various minnows (*Cyprinidæ*). In the flags in the south end of the field, found sunfish and crappie fry in water 2 to 4 inches deep. They are shut off now from any connection with Lynch Slough or Thompson's Lake, making it practically certain that they will perish with further drying.

In the soft mud of the nearly dried-up bottom of the two "guts" in the south end of the field, draining the field southward into Lynch Slough, we found numerous dead crayfish and snails, but no carp. It is through these two "guts" that the fry seem most likely to have gone out of the field—if they went out at all—as the water receded between June 5 and 20.

July 7. Took 200 specimens of young carp, 1 to 2 inches long, at the head of Liverpool Lake, west shore, with one haul of the 120-ft. minnow seine. They were taken in water 1 to 3 feet deep, moderately clear of vegetation, but with a thick fringe of *Ceratophyllum* and *Spirogyra* along shore. The bottom is mixed hard clay and black mud, with some vegetation as far as 100 feet out from shore; the water is slightly turbid, from the strong current flowing in from the river through the inlet ditch opposite Liverpool.

Among the specimens taken were a good many of the mirror and leather varieties. The large number saved in the haul with ¼ inch mesh, through which many probably escaped, suggests the probability that there were in all several thousand in the shallow water at the northwest end of the lake, below the inlet ditch.

July 12. Took four specimens of young carp (1 to 2 in. long) in one haul of a 15-ft. seine, on the gravel point below Sam Bishop's, on the west shore of Quiver Lake, in *Ceratophyllum.*

July 24-31. Took a few young carp, 1 to 2 in. long, on the west shore of Illinois River, opposite Quiver Beach, along the edge of the muddy bank, in *Ceratophyllum.*

August 3. Allen tried the haul at head of Liverpool Lake, where 200 carp were taken July 7. No young carp obtained. Water has fallen 2 feet, and the vegetation zone is nearly all out of water.

August 9. Tried the west shore of Illinois River, opposite Quiver Beach, where we took a few young carp July 24-31, but got none. Water has gone down one foot, and left most of the *Ceratophyllum* high and dry.

August 10. Tried the head of Liverpool Lake again. No trace of young carp. The water has receded, leaving the vegetation zone dry.

August 11. Tried half a dozen hauls with 120-ft. seine in Clear and Mud lakes and Courtwright Slough, but got no carp, young or old.

August 10-12. Tried various hauls in Shepard Island Slough and Bath Lake, but found no trace of young carp.

August 25. Half a dozen specimens of young carp, 2 to 3 inches long, taken by Mr. Hart in a slough below the Chautauqua barns when the slough was drained in the course of mosquito work. The slough contains some smartweed and *Ceratophyllum.*

September 7. One young carp 6 inches long (1909 spawning?) taken from "Black Bill" Shafer's seine, head of Thompson's Lake.

NINETEEN HUNDRED AND ELEVEN

Field work began April 15. Weather generally chilly between April 15 and 30, cloudiness and winds not favoring spawning activity and interfering a good deal with field observations under water. Water temperatures on spawning grounds reached 60° to 66° Fahr. between April 20 and 25, and dropped back to 58° as a result of a heavy frost at the end of the month. The river rose from 10.2 to 10.6 feet between April 15 and May 1.

April 25. Carp are on the spawning grounds at head of Flag Lake, and giggers are at work. (A boat-load of gigged carp were brought to Havana the next day.) No eggs found today.

May. The weather was fair and dry throughout the month of May, with the river gradually falling from 10.6 feet on the first to about 9 feet on the last of the month. The first ten days were rather chilly to moderate, with water temperatures increasing from 58° to 74° Fahr. Temperatures mounted rapidly between May 10 and 18, the air touching 90° and the water 81° on the last date. By May 22, water temperatures on the spawning grounds had reached 86°.

May 3. A few carp eggs were found today in the north end of Danhole's field, in water 10 inches deep, on bog rush. Also a few found at the northeast end of Flag Lake, attached to dead flag at and below the surface in 2 feet of water. The indications are, however, that only a few carp have spawned, and that the greatest spawning activity is yet to come, with warmer weather.

May 5. The river gage is nearly two feet lower than on the same date last year, and falling. Danhole's field is under water only at the north and south ends, about 100 acres in all—a sixth of the total area—being flooded. Carp eggs are thick on live bog-rush and dead grass and drift in the north end of the field, but 98 or 99 per cent. are fungused. The water is 6 to 10 inches deep, with a temperature of 62°.

Several large carp were seen splashing this afternoon on the west shore of Thompson's Lake, just below the Thompson's Lake Club

House. They occasionally jump clear of the water, with body vertical, head up, "treading water with the tail." It is a warm, sunny afternoon.

May 6. Visited the lower end of Sangamon Bay, six miles north of Beardstown, today. Towards noon the mud flats here and at the head of Pluckimen's Slough, several hundred acres in extent, were alive with spawning carp. Probably not less than a thousand fish were spawning. The water is shallow, 1 to 3 feet deep, and pretty well filled with smartweed, *Ceratophyllum,* and *Potamogeton;* also a good deal of live willow. Spawning females, with eggs running, are easily taken with a dip-net. The "coursing" of the pairs and trios (one female and one male, or one female and two males) is easily observed, the fish sometimes passing close enough to rub one's boots. The males are always smaller than the female, and swim a little lower, with the nose under her belly, pressed close up against her. The grass and water-weeds are hung with myriads of eggs, from freshly spawned ones to those nearly ready to hatch. Spawning must have been in progress here for several days. Of the older eggs, it is noted that the per cent. fungused is very small, probably not over 10 per cent. This may be connected with the freshness of the vegetation among which the eggs were spawned.

May 8. About a hundred carp were seen spawning at the head of Danhole's field today, in water 8 to 10 inches deep, and another hundred on the west side of Thompson's Lake, a quarter of a mile above Warner's Cut, in water 2 to 3 feet deep, full of smartweed and "blanket-moss" (*Spirogyra* and *Cladophora*). Small numbers were seen spawning at the head of Flag Lake and on the west shore of Thompson's Lake, below the club house.

May 16-17. The river has fallen a foot since May 1, and is now two feet below the level of this date last year. Danhole's field is rapidly drying up. The north end is padded down with a blanket of rotting weeds and pond scum. The only egress for the carp fry is through a small opening into the Crabtree ditch, a quarter of a mile south of the northeast corner of the field. The temperature of water 2 to 6 inches deep is 89° to 92° Fahr.

May 22. Visited Danhole's field to search for carp fry. The field is now almost wholly without water, with the bottom a soft muck, except for small depressions, 1 to 3 feet in diameter and occasionally larger, in which water ½ inch to 4 inches deep is still standing. The temperature of the water in these holes is 92°. There are thousands of dead carp fry in recently dried-up holes. In some of the holes with water ½ inch to 3 inches deep we found apparently healthy carp, ½

to ¾ inch long, in a water temperature of 92°. In a single depression one foot in diameter, with water only ½ inch deep, there were fifty fry, some dead, some nearly dead, and others flopping about wildly. It is impossible to estimate with any accuracy the number of fry that have already perished. It is surely hundreds of thousands, possibly millions.

May 25. Saw several carp spawning this morning in the head of Dierker Lake. Fresh eggs, and those nearly ready to hatch, are abundant on *Ceratophyllum* and dead drift.

May 26. Carp fry ½ to ¾ inch long are abundant today in the head of Liverpool Lake, west shore, just below the inlet ditch, in 2 to 6 inches of water, in vegetation. They are feeding at and very near the bottom. A cheese-cloth seine used in water 1 to 2 feet deep, away from the shore and out of the vegetation zone, does not get them.

May 26. Searched for carp fry today along the west shore of Thompson's Lake, from half a mile below the club house to Big Cove. Found them abundant in "blanket-moss" zone, along the edge of the lake, in water 4 to 8 inches deep. By lifting up "moss" we can see them feeding on the bottom. Some also are feeding in the moss near the surface. The temperature of the water is 89° to 90° Fahr. in the upper two inches; 81° to 83° in the lower two inches. In a brush patch just above the Big Cove, fry are abundant in moss-choked water 3 feet deep. Picked them up with a tin cup from surface moss, and got large numbers with Ekman dredge from the bottom, under the moss.

June. The month of June was unusually hot and dry, air temperatures ranging from 85° to 98° except for a short cool spell June 12 and 13. The river gage was at 8.4 feet on June 15, fully three feet lower than on the same date last year, and had dropped to 7.9 feet by June 21. Danhole's field is all dry except the lotus pond. The lakes are so low and choked with vegetation as to make navigation difficult with either skiffs or launches. Heavy rains June 25 caused a temporary rise of a few inches. Field operations of the month included some search for carp fry, but without success in any instance. Actual observation of carp spawning was made as late as June 2, and reports of spawning as late as June 8 were received from fishermen.

June 2. A dozen or so carp spawned about a drift pile in Flag Lake Swale this morning, in water 5½ feet deep. Went to the spot immediately with William Selby, fisherman, who brought in the report, and got an abundance of fresh eggs. Hatched these in the laboratory, and kept them until a satisfactory determination of the species was possible. While buffalo are believed to spawn frequently in water as deep as this, carp certainly do not do it often.

June 5-8. James Trent, fisherman, reports carp spawning in considerable numbers in Clear Lake, on the "Middle Ground"—a brush-covered ridge under shallow water.

SEARCH FOR YOUNG CARP, SEASON OF 1909

Young carp under six inches seem very rare about Havana. From July 1 to December 31 we succeeded in finding them only twice, and in very small numbers: once in one of the mud-bottom "horseshoe" ponds north of Spoon River bridge (C., B. & Q.); and once in a small pond along the Crabtree dredge ditch opposite the foot of Thompson's Lake.

FEEDING HABITS OF YOUNG CARP IN FIELD, AND IN LABORATORY AQUARIA, 1910

May 25. Young carp ½ to ¾ in. long observed to snap at and swallow large *Entomostraca* (*Cladocera* and *Copepoda*), in laboratory aquarium.

July 14. Specimens 1 to 1½ in. long, observed to attack and swallow, with difficulty, full-sized specimens of a small amphipod crustacean (*Hyalella knickerbockeri*), 3 to 5 mm. long, in laboratory aquarium.

August 19. In a laboratory feeding experiment made August 19, young carp 1 to 2 inches long were fed mixtures of coarse plankton—*Entomostraca*, *Hyalella*, small insect larvæ, *Wolffia*, etc.—and killed after thirty minutes. One specimen 1⅝ in. long was examined, and had eaten several *Hyalella* and one *Cyclops*, but no *Wolffia* or other vegetation.

Acc. No. 28551. The food of two specimens of this collection, made in Danhole's field June 3, 1910, was as follows: One (½ in. long) had eaten nothing but three large *Cyclops;* the other (⅝ in. long) had eaten 1 *Cyclops*, 1 *Alona*, 4 ostracods (*Cypris?*), and a trace of *Spirogyra*. It was noted that *Cladocera*, *Copepoda*, and *Ostracoda* were very abundant June 3 in cheese-cloth seine-haul.

Acc. No. 28569. A specimen 1¼ in. long taken from the head of Liverpool Lake in July, 1910, had gorged itself with about a dozen *Cyclops*. No vegetation had been eaten except a trace of *Spirogyra*. Nothing of the nature of mud was to be seen in the stomach.

Is it possible that the reason for the sudden disappearance of the carp fry from this place between July 7 and August 11 was that they had exhausted the supply of *Entomostraca*—to which they had accustomed themselves for some weeks—and that they left to find new feeding grounds?

SPAWNING DATES, HAVANA AND VICINITY, 1910 AND 1911

1910

April 8-20. Vicinity of Havana (reported by fishermen; localities various).

May 1-10. Danhole's field. Large numbers spawned between these dates. Eggs found.

May 10. Schulte's field. Eggs found.

May 10-11. Beck's Swale and ponds. Eggs found.

1911

April 25 Head of Flag Lake. Breeding males and females on spawning grounds. Giggers at work. No eggs could be found.

May 2-3. Danhole's field. Fresh eggs found.

May 2-3. Head of Flag Lake. A few dozen observed spawning. Eggs found.

May 6. More than 1000 seen spawning in Sangamon Bay. Many fresh eggs taken. Spawning females taken with dip-net.

May 8. About a hundred seen spawning on the west side of Thompson's Lake; a few at head of Flag Lake; and a hundred in Danhole's field.

May 25. Dierker Lake. A few dozen seen spawning.

June 2. Flag Lake Swale. About a dozen spawned. Eggs taken and hatched.

June 5-8. "Middle Ground", Clear Lake. Fishermen report considerable numbers spawning.

SITUATIONS SELECTED FOR SPAWNING

1. Overflowed fields and marshes (cultivated previous to opening of the Drainage Canal in 1900) grown up with bog rush, smartweed, cut-grass, and "flag" (*Scirpus*); depth of water (April and May, 1910 and 1911) 1 to 2 feet. Danhole's and Schulte's fields.

2. Shallow ditches and ponds, mud bottom and smartweed; water 1 to 2 feet deep, 1910. Beck's ponds.

3. Shores of open lakes, in vegetation zone; flag, smartweed, *Potamogeton,* and *Ceratophyllum;* water 1 to 2 feet deep, 1911. Northwest shore of Flag Lake; west shore of Thompson's Lake; head of Dierker Lake.

4. Overflowed mud flats, grown over with willows, grass, and *Ceratophyllum;* water 1 to 3 feet deep, 1911. Flats at south end of Sangamon Bay and head of Pluckimen's Slough.

5. Swales, among willows and "buck brush"; water 4 to 5 feet, 1911; too deep for rooted aquatics; occasional *Ceratophyllum*. Flag Lake Swale.

ESTIMATED NUMBERS SPAWNED, HATCHED, FUNGUSED, AND MATURING, DANHOLE'S FIELD (600 ACRES), 1910

Number of eggs present May 9, 1,451,818,500.

Per cent. of eggs with eye-spots May 12, ten.

Per cent. of fungused eggs in field (to beginning of hatching), ninety.

Number of eggs hatched, 145,181,850.

The percentage of eggs fungused in the north end of Danhole's field in May, 1911, was much greater than in 1910, probably equaling 98 or 99 per cent. This high ratio was probably due largely to the abnormal lowness of the water and unseasonable warm weather. Both in 1910 and 1911, Danhole's field contained a great deal of rotting dead grass and flag. In laboratory lots it was noted that eggs hatched better in jars containing fresh living algæ and *Ceratophyllum*, and free from dead grass and trash. Eggs spawned in *Ceratophyllum* in Sangamon Bay, May, 1911, showed a relatively small ratio of fungus, probably less than 25 per cent.

H. M. Smith (quoted in *Fishing Gazette*, June, 1910), has expressed the opinion that one out of a thousand salmon hatched comes to maturity. On this basis, out of 145,181,000 carp hatched in Danhole's field in May, 1910, 145,181 would reach maturity, and it would take only 28 times this number to replace the annual take-out of carp from the river by fishermen (about 20,000,000 lbs. for the whole state in 1908, at an average weight of 5 lbs. each, equivalent to 4,000,000 adult carp). In other words, it would take only 28 marshes the size of Danhole's field to replace the present annual catch on the basis of one out of a thousand hatched reaching maturity. The ratios actually realized in seasons of favorable water-levels are probably much better than this, both in *per cent. hatched* (after deducting for fungus) and in *per cent. of fry that reach maturity.*

HABITS AND LOCAL PREFERENCES OF FRY AND FINGERLINGS

1. *Marked preference of fry for animal food.*—Specimens ½ to ⅝ inch long from Danhole's field, June 3, 1910, had eaten large quantities of *Cyclops, Alona,* and an ostracod, with a trace in some cases of *Spirogyra*. One had eaten nothing but large *Cyclops*. A specimen 1¼ inch long from the head of Liverpool Lake, July, 1910, had

gorged itself with *Cyclops*. It had taken no vegetation except a trace of *Spirogyra*, and nothing of the nature of mud was to be seen in its stomach. In the laboratory, young carp ½ to ¾ inch long were observed to snap at and swallow large *Cladocera* and *Copepoda*, and specimens 1 to 1½ inch long were seen to attack and swallow, with difficulty, full-sized specimens of *Hyalella knickerbockeri*, 3 to 5 mm. long. In August, 1910, several young carp 1 to 2 inches long were fed in the laboratory a mixture of coarse plankton, including *Entomostraca*, *Wolffia*, etc., and killed after thirty minutes. Specimens examined had eaten greedily of the *Entomostraca*, but had taken no *Wolffia* or other vegetation.

2. *Apparent preference of fry and fingerlings for feeding grounds with some bottom-covering of vegetation (presumably because of the animal organisms living among the vegetation).*—Work with the cheese-cloth seine in Danhole's and Schulte's fields in May, 1910, indicated that fry ⅜ to ¾ inch long feed by preference very near the bottom. The situations studied were all shallow, 1 to 2 feet deep, more or less densely filled with short bog-rush, among which was a rich entomostracan plankton. Fry were *never* observed *swimming at or near the surface, in open water*, as do the fry of bass, sunfish, and various native *Cyprinidæ*. In May and June, 1911, likewise, it was our experience that the fry were most likely to be found along the very edges of lakes such as Thompson's, Liverpool Lake, etc., in water 6 inches to 1 foot deep, choked with bog rush, algæ, or other vegetation. Large numbers were observed feeding on the bottom under veritable blankets of algæ, which had to be lifted before the fry could be seen. At no time did we find carp fry in open water with mud or sand bottom. We found them in Thompson's Lake, May, 1911, in water as deep as 4 feet, but only where there was a rich growth of vegetation. In Thompson's Lake, May, 1911, in intertangled algæ and *Potamogeton*, reaching from bottom to surface in 4 feet of water, we found them at various levels, from bottom to surface, but those at and near the surface were held up to a great extent by the algæ, and were not swimming free. In the search for fingerlings in July and August, 1910, when we could find them nowhere else, we were pretty sure of getting them in the narrow *Ceratophyllum* zone on the west shore of the Illinois River, opposite Quiver Beach. This *Ceratophyllum*, rolling against a mud bank in 1 to 2 feet of water, was swarming with a small amphipod, *Hyalella knickerbockeri*, on which the young carp were feeding.

THE FRY'S STRUGGLE FOR EXISTENCE FROM HATCHING TO FINGERLING STAGE

1. *Natural enemies.*—Large numbers of gar, bass, and pickerel (grass pike) frequent the marshes used by carp for spawning grounds and themselves spawn there. The pickerel are in the fingerling stage by the time the carp are ½ to ¾ inch long. The bass and gar spawn at about the same time as the carp, in general, but the large size of the mouth of these species and their well-known predaceous tendency, doubtless make them destructive enemies of at least the later-spawned carp fry.

2. *High temperatures on the spawning grounds.*—By May 22, 1911, water temperatures in the marshes and overflowed flats about Havana had reached 86° Fahr.; but some fry were found still alive at that time in drying-up holes in Danhole's field, in water registering 92°, as likewise in small puddles left from the drying-up of Beck's ponds, July 1, 1910.

3. *Landlocking and drying up of spawning grounds before fry are old enough to escape.*—Large numbers of fry perished from these causes in May, 1911, (Danhole's field,) and in June and July, 1910, (Beck's ponds). To what extent their instincts protect young carp of proper age from the danger of falling water is not altogether certain. The bottom- and vegetation-loving habit of the fry, from hatching to the fingerling stage, is probably always a source of danger. That great numbers of them fail to take care of themselves when 4 to 6 weeks old and from ½ to ¾ inch long, is apparently proven by the observations made in Danhole's field in May, 1911. The slightly greater age of the fry when first critical levels were reached in the last week of June, 1910, was probably the only thing that prevented even greater destruction then.

There are also indications of a general nature that conditions in the lakes and sloughs about Havana, and perhaps at other points along the river, are now less favorable to the development and maturity of carp fry than they were previous to the opening of the Chicago Drainage Canal in 1900. Previous to 1900 there was much vegetation in what is now open water. The shallower lakes then offered excellent opportunities for spawning, many of them over considerable areas well away from shore, and in all cases with deeper water always within easy reach. Now in most of the lakes the vegetation is reduced to a narrow zone along portions of the shores, and the newly formed marshes due to the temporary overflow of the old lake-banks offer the most extensive and suitable territory available in April and May for spawning purposes; but the flatness and shallowness and im-

permanency of these new marshes is likely, except in spring seasons of more than average water levels, to be a source of serious danger to the fry before the fingerling stage is reached. In Danhole's field the critical range of river levels for the young carp lies between 9.6 and 9.0 feet (Havana gage). At 9.6 feet this 600-acre tract is practically landlocked except for a single small opening into the Crabtree dredge ditch, toward the northeast corner of the field; and between that level and 9.0 feet destruction of fry under six weeks old is known to proceed on a large scale, as perhaps also some destruction of fry still older. The stage of 9.6 feet was reached on May 17 in 1911, and great destruction resulted in the week following. The same level was not reached till the last of June in 1910, when the greater age and size of the fry seems to have permitted most if not all of them to escape; but it should be noted here that the field observations of the spring and summer of 1910 were broken off from June 3 to June 23, and that our history of the fate of the fry that season is consequently incomplete.

A full list of dates follows, on which critical river levels for the fry in Danhole's field were reached from 1900 to 1911 inclusive. It should be noted in this connection that at 9.6 feet the field is practically landlocked, and that at 9.0 feet the destruction of fry by drying is about completed. The unmarked years are those in which it is certain, on evidence of the observations of 1910 and 1911, that more or less extensive destruction of fry went on in such areas as Danhole's field. The interrogation points indicate seasons in which the amount of destruction that occurred is uncertain, depending very probably on the date of spawning of the various broods and their size at the time the critical level was reached. The years preceded by an asterisk are those in which it is reasonably certain that the fry escaped, the number of these years being only three out of a total of twelve.

DATES OF CRITICAL RIVER LEVELS FOR FRY IN DANHOLE'S FIELD, 1900-1911
(Havana gage)

Year	Date of fall to 9 6 ft.	Date of fall to 9.0 ft.
1900	May 12	May 23
1901	May 9	May 13
1902	April 17	April 23
?1903	July 3	July 7
1904	June 9	June 23
?1905	July 11	July 15
1906	May 18	May 22
*1907	Nov. 1	Nov. 10
*1908	July 23	July 27
*1909	Aug. 4	Aug. 9
?1910	June 29	July 4
1911	May 17	Before May 31

POSSIBLE REMEDIAL MEASURES

1. *Artificial regulation of water levels on the most important breeding grounds, especially during the critical period of such seasons as* 1900, 1901, 1902, 1904, 1906, and 1911; *and provision of better means of escape for the fry at the beginning of the critical period, by ditching.* It is possible that something could be accomplished in both these directions by cooperation of the Fish Commission with some of the better-situated agricultural drainage districts.

2. *Protection of growing fry against enemies, particularly bass, gar, and pike.* The State Fish Commission has already taken up the question of gar extermination; but until some suitable method of segregation in the Illinois river backwaters of the angling (bass) and commercial (carp and buffalo) interests is adopted, the bass will continue to be a very destructive enemy of the fry of the two commercial species—carp and buffalo.

3. *Protection of eggs against destruction by fungus.* Our observations show clearly that destruction by fungus is least among eggs spawned in clean water, bearing a naturalized growing aquatic or semi-aquatic vegetation. As a result of the higher water-levels since the opening of the Chicago Drainage Canal, in 1900, the breeding grounds of the carp have been pushed back, to a great extent, into newly made marshes, not yet adapted to submergence, and still choked every spring with dead and rotting land plants. It is possible that in time this matter will adjust itself to a certain extent. Such a readjustment would be assisted by any measures taken to insure, artificially, greater permanence of levels in these areas.

On the Breeding Grounds, watching Movements of Fish, and searching for Fish Nests and Fry.

ARTICLE VIII.—*Observations on the Breeding Habits of Fishes at Havana, Illinois, 1910 and 1911.* By R. E. RICHARDSON.

In this paper is presented a summary of all our notes of the seasons of 1910 and 1911, concerning the breeding of fishes other than carp. They were made principally at Havana, Illinois, but include in a few cases observations made in the vicinity of Beardstown, Meredosia, and Grafton.

PADDLE-FISH (*Polyodon spathula*)

The paddle-fish is now rare at Havana, but it is considerably more abundant at Meredosia and other points below the La Grange dam. Meredosia fishermen believe that it spawns every year in Meredosia Bay. David McLean, an experienced and unusually intelligent fisherman there, says that paddle-fishes do a great deal of splashing in the middle of the bay in June of each year, and that they afterwards seem to leave the bay for the deep water of the Illinois and Mississippi.

SHORT-NOSED GAR (*Lepisosteus platostomus*)

Fifty eggs of short-nosed gar were found May 12, 1910, hanging to grass and smartweed in Schulte's field, Havana, very near or above the surface, where the depth of the water was one foot. Some of them were high and dry except for such moisture as they might get by capillarity. These eggs were taken into the laboratory, and all hatched at the end of eight days. Freshly spent females were taken with our trammel-net in the "Flag Pond" south of Lynch Slough, May 19, 1910. This marsh is thickly grown up with *Scirpus*. One female, 18 inches long, squirted eggs over the net, and they adhered to it firmly. We took this specimen to the laboratory and removed about 200 eggs from her. At 6 p. m. these eggs were sprinkled over the bottom of a white enameled pan, to which they adhered, and were washed with a little water containing milt squeezed from the rather hard testis of a large male taken that afternoon in the same place. At the end of twenty hours, examination showed that all these eggs were impregnated. They began to hatch May 27, toward evening, and by noon of May 28 were all hatched except for a loss of about five per cent. by fungus. Apparently fresh eggs were found May 8, 1911, on trash and vegetation on the bottom, in water

three feet deep, at the head of Flag Lake. These were brought to the laboratory, and hatched in from six to eight days. They were found in a locality frequented by spawning carp and black bass. Hundreds of short-nosed gar were seen spawning May 10, 1911, in shallow water, one to three feet deep, along the east shore of Meredosia Bay, half a mile above the Fish Hatchery, on ground on which carp had deposited great numbers of eggs only three or four days before. They were "running" in pairs, each female with a smaller male attending her, with nose held close under her belly, one or both occasionally flirting the tail or the whole body out of the water. Females full of nearly ripe eggs were taken in Quiver Marshes, Havana, in 1910, as late as June 30; but the great majority of the females taken in trammel-net drives at that date had spawned.

Fry hatched in the laboratory had the yolk sac absorbed at the end of seven days. At the age of ten days they were still observed to lie inert on their sides on the bottom of the aquarium, or to hang to the sides of it with their oral suckers. When between ten and sixteen days old they could not be seen to make any movement for securing food; but a sixteen-day specimen, ¾ inch long, was found on dissection to have eaten seventeen large specimens of a small crustacean, *Scapholeberis mucronata,* and nothing else. These *Entomostraca* were apparently selected separately from among a mixed plankton, and must have been taken by instantaneous movements, when no one was near to see what was happening.

Fry and fingerlings from ⅝ to 3½ inches long were taken in 1910 and 1911 at the following places and dates: May 10, 1911, ⅝ inch long, abundant in water 2 to 3 feet deep, among willows, full of weeds, at head of Meredosia Bay; May 25, 1911, ¾ inch to 2½ inches long, in shallow water, along shores of Dierker Lake; May 26, 1911, 2¼ inches long, Big Cove, Thompson's Lake; June 22, 1910, 1¾ inches long, Persimmon Point, near mouth of Quiver Creek; and July 7, 1910, 3½ inches long, head of Liverpool Lake.

The noticeable rarity of gar fingerlings and fry in collections is probably to be explained in part by their extreme slenderness, which permits them to escape through the meshes of ordinary minnow seines, but is perhaps due in greater measure to their solitary habit. All that we took in 1910 and 1911 were caught singly; and without exception, all young gars seen during these two seasons were floating at or very near the surface of the water, in the sun, sometimes with the back exposed. If disturbed, they dart downward in a flash; but usually return to the same place a few seconds or minutes later to take up their station. A second or third trial with a dip-net is often successful if the first is not.

Immediately after the close of the spawning season, or about May 25 to June 1, great numbers of adult short-nosed gars are to be seen in the river, swimming very near the surface and breaking water at short intervals to seize emerging gnats and Mayflies. This kind of activity is visible on sunny days at almost any time through June and most of July; but during the five or six weeks preceding its start, the river is nearly clear of gars, in consequence of their congregation for spawning purposes in the lakes and marshes. More than once between June 1 and July 15, both in 1910 and 1911, Allen and I had in sight at once as we went up the river in the launch as many as fifty large gar—at least twenty-five on each side of the boat. If we could have looked ahead also, we should doubtless have seen another twenty-five, making seventy-five in a radius of 60 feet. It has occurred to me that advantage might be taken of this habit of gars to destroy them. It is at least probable that very large numbers of them could be caught, without danger to other fishes worth mentioning, by hanging fine-meshed gill-nets so floated as to fish only the upper 18 inches to 2 feet of the river. Certainly if our commercial fisheries are to be properly conserved, stringent measures will have to be taken against these "weeds" and "wolves" among fishes.

Dogfish (*Amia calva*)

Dogfish nests with eggs nearly ready to hatch—the embryo turning inside the egg—were found April 20, 1911, in Weed Prairie, an overflowed flat south of Thompson's Lake, between Deep and Lynch sloughs. The nests were in water 2½ to 3 feet deep, choked with smartweed, "flag" (*Scirpus*), and *Cladophora*. They were about two and a half feet in diameter, and nearly round, and were excavated to a depth of about four inches, exposing grass roots, to which many of the eggs adhered. The nests contain from 2000 to 5000 eggs each. The male fish, about 20 inches long, could be seen hovering over each nest. One male allowed us to lower the water-glass to within six inches of his back. Eggs which were probably spawned about April 5 or 6 hatched in the nests between April 21 and 23, when the water temperature stood at about 60° Fahr. It was possible to determine only roughly the percentage of fungused eggs in the nests. They were probably less than fifty per cent.

Eggs brought to the laboratory hatched at the same time as those in the field and had the yolk sac absorbed by April 27. By April 29, the fry were swimming near the surface of the water in the aquarium, and when fed mixed small plankton, could be seen jumping, and opening and closing their mouths to catch the minute morsels.

Fry were still in nests, attended by males, in Weed Prairie, April 28; and the use of a thirty-inch pipette showed a rich plankton of small crustaceans in the very bottom of the nest. The most abundant forms were *Pleuroxus, Alona,* and *Chydorus,* possibly attracted there by decaying fungused eggs. On April 28, the temperature of the water was 61° Fahr. The fry left these nests at some time between May 4 and May 15.

Older fry and fingerlings were seen or captured on various dates between May 3 and May 23, 1911. May 3, a school of 500 to 600 fry, ½ inch long, was seen at the head of Flag Lake. May 5, a school of about 500 fry, ⅝ inch long, attended by a male 15 inches long, was seen in very shallow water among dead flag, at the head of Danhole's field. This male was not easily frightened, and moved away very leisurely, stopping only fifteen feet away, in full sight of us. These fry were probably considerably older than those in nests found in Weed Prairie. They must have hatched soon after April first, and were probably spawned soon after March 10, if not earlier. At this age the young swim low, about half way between the surface and bottom, in water 1½ to 2 feet deep, and if unattended by the male they might easily be mistaken for tadpoles.

Fingerlings 2 to 2¼ inches long were taken May 22, 1911, in the head of Danhole's field, in weeds, in water only 6 inches deep, and May 23, 1911, in Quiver Marshes, 150 yards above the mouth of the new dredge-ditch, in water of about the same depth, choked with weeds. The last school, of about 200, was still attended by the male. A dozen of these fingerlings were put into an aquarium in the laboratory, where they devoured in one night more than fifty minnows ½ to ¾ inch long. Fry, ⅜ inch long, from late-spawned eggs, and probably only a week or ten days out of the nest, were taken May 23, 1911, in open water 18 inches deep, in a still pocket opening from lower Quiver Creek. These fry were apparently unattended by a male, and were swimming just above the bottom.

Buffalo (*Ictiobus cyprinella* and *I. bubalus*)

In 1910 the condition of market specimens of both the red-mouth and quillback buffalo indicated that these species had spawned as early as April 15. May 15, 1911, males of the red-mouth buffalo kept several weeks in a crib belonging to the Havana Fishing Company, were spilling milt. There were no females in the crib, and the spawning of the males had probably been retarded somewhat by confinement. At Grafton, May 29, 1911, the condition of market

specimens indicated that about nine out of ten buffalo of all species had spawned.

A good deal of time was devoted in the spring and summer of 1910 and 1911 to the search for buffalo fry and fingerlings, though practically without success. Various reports of spawning of small bunches of buffalo proved, when followed up, to have referred to carp. Old spawning grounds, frequented by buffalo in thousands at breeding time some ten or fifteen years ago, do not now seem to be visited at all by buffalo. In fact the decrease of buffalo in the Illinois River seems to have been going on steadily during the last thirty years, and has been particularly noticeable since the completion of the lower locks and dams at La Grange (1889) and Kampsville (1893), the introduction and rapid increase of European carp, and the opening of the Chicago Drainage Canal. In 1881, Ira Sargent, an old fisherman still living in Havana, took 251,000 pounds of buffalo in Moscow Lake, below Bath, in a single haul with a 700-yard seine. Now the catch of buffalo at Havana and Beardstown probably runs on the average considerably less than 50 lbs. to 1000 lbs. of carp. The true reasons for this great decrease in buffalo are not at present wholly clear. That the construction of the lower Illinois river dams serves to some if not to a great extent to keep buffalo from coming up the river to spawn as formerly, is not unlikely, and seems to be indicated by such facts as the present rarity of observations of buffalo fry and fingerlings above the La Grange dam and their much greater abundance at points below La Grange, and more especially at points below Kampsville. The preference of buffalo for water of good depth and their timidity in the face of obstructions that carp would disregard, are pretty well established by the testimony of many observers, both fishermen and naturalists. That actual competition with the European carp for food may have a bearing on the decrease of buffalo is less certain, but is suggested by the steady change in the ratio of carp to buffalo in the catches at Grafton and Alton during the last seven or eight years. As late at 1904 and 1905, many more buffalo than carp were taken at these places. Now the ratio is reversed, Grafton fishermen informing me in 1911 that they got hardly more than 100 lbs. of buffalo to 1000 lbs. of carp. That the fouling of the bottom of the Illinois River in the last twenty years with city wastes may have something to do with the decrease is not out of the range of possibility. In this connection it is interesting to note the testimony of fishermen who have recently fished in both the Sangamon and the Illinois that at the present time buffalo are relatively more abundant and of finer quality in the Sangamon than in the Illinois River.

Chub-sucker (*Erimyzon sucetta oblongus*)

The fry of this species, ¾ to 1¼ inch long, were abundant in Quiver Marshes in late May and early June of 1910 and 1911. The fry swim in schools of fifty to a hundred or less, at about the same level as bass fry, and their coloration, owing particularly to the black side-stripe, is such that they are not always readily distinguished at the first glance from fry of large-mouthed bass.

Yellow Bullhead (*Ameiurus natalis*)

Examination of market specimens, May 19, 1910, showed the yellow bullhead well advanced—probably within less than a week of their spawning time. June 3, 1911, eggs ran from market specimens examined. That spawning was in progress was indicated also by a great decrease in the trot-line catch within the few days preceding.

Speckled Bullhead (*Ameiurus nebulosus*)

May 19, 1910, market specimens of the speckled bullhead uniformly appeared considerably less advanced than the yellow and black bullheads. May 27, 1910, a female brought in by Allen from Deep Slough May 23, spilled eggs in the tub in which she had been placed for observation.

May 28, 1910, trot-liners generally quit work because of failure of the bullheads to bite while spawning. May 31, 1910, we found a nest in Quiver Marshes containing a hundred or so recently hatched fry, probably not much more than three days old, the yolk sac still being large. This nest was in water 2½ feet deep, among *Ceratophyllum* and rushes. It was guarded by a 14-inch male, who allowed the water-glass to be pushed down almost in contact with his back.

In 1911 some specimens in market had eggs running as early as May 14. Between May 27 and June 3 they were reported by trot-liners generally as spawning. On July 2 we found two schools of 100 young each, 1¾ inch long, attended by the male, in Becks' ponds and Danhole's field.

Black Bullhead (*Ameiurus melas*)

May 19, 1910, market specimens of black bullheads were in about the same condition as the yellow bullhead already mentioned. They were apparently within less than a week of spawning.

Stone Cat (*Schilbeodes gyrinus*)

A female stone cat, full of nearly ripe eggs, was taken as late as July 1, 1910, near the head of Quiver Lake near the east shore.

Grass Pike (*Esox vermiculatus*)

Large numbers of grass-pike fingerlings are easily taken in May and June in Danhole's field. By the 25th of May, 1910, they had grown to a length of 2 to 2½ inches, and were doubtless, before that time, formidable enemies of the myriads of carp fry in the field, practically none of which were over ⅝ inch long on the first of June.

Top-minnows (*Fundulus notatus* and *F. dispar*)

On May 25, 1911, about two dozen *Fundulus notatus,* males and females, were observed swimming actively, pursuing one another, and occasionally jumping clear of the water, in weed-filled shallows toward the head of Dierker Lake. Two males at times pursued the same female, one trying hard to drive the other off. Examination of the females showed the ovaries full of eggs of large size and loosened from the membrane.

Gravid females of *Fundulus dispar,* on the point of spawning and attended by males, were taken May 23, 1911, in shallow water, full of weeds and algæ, just outside of Riley Smith's Marsh, above the head of Quiver Lake.

Silverside (*Labidesthes sicculus*)

During the second week of June, 1911, the fry of this species, ¼ to ⅜ inch long, were abundant, in schools, in water 2 to 3 feet deep, on the ridge between Flag and Thompson's lakes. They swim near the surface, with a very characteristic wriggling movement. They seem to keep to the open spaces between the clumps of smartweed and *Potamogeton.*

Speckled Crappie (*Pomoxis sparoides*)

May 2, 1911, a nest of this species was found in water 10 inches deep near the north end of Danhole's field. It was hollowed out under the leaves of a water-parsnip, and surrounded by smartweed and bog rush (*Juncus*). Some of the eggs were adhering to fine roots in the bottom of the nest, but most of them were on the leaves of the water-parsnip, at a level of 2 to 4 inches above the bottom of the nest.

The nest was guarded by a male 6 inches long, who was so gentle that we could reach out a hand to within three feet of him before he moved away. Eggs taken to the laboratory hatched May 3 and 4. Both eggs and newly hatched fry are even smaller than those of the blue-gill sunfish; and the great transparency of the new fry, along with their small size, makes it very difficult to see them in an aquarium.

Warmouth Bass* (*Chænobryttus gulosus*)

May 23, 1911, a dozen nests of this species were found in a circle of ten feet radius about the base of a large willow-tree in Deep Slough, in water 6 to 10 inches deep. The bottom was sand and mud, almost free of vegetation, but pretty well covered with fine dead twigs and dead leaves. The nests were very small, only 4 to 6 inches across in most cases, and of irregular shape; and all bore evidence of being very quickly and carelessly made, as compared with nests of bluegills and bass. Many of them would scarcely be recognized as nests if the male were not seen over them or a glimpse obtained of the white specks that indicate fungused eggs. There was practically no excavation of the soil of the bottom, merely the looser trash and leaves being brushed away, and not always all of that. Some of the males were exceedingly gentle, allowing us to touch them with a 30-inch pipette before moving away. We found no bluegill so gentle as this. Some of the nests contained new fry with yolk sac still large; others were full of eggs nearly ready to hatch. Eggs from these nests taken to the laboratory hatched during the night of May 23-24. Two nests containing fry with yolk sac nearly gone, were found in a similar situation in Lynch Slough May 26, 1911.

Orange-spotted Sunfish (*Lepomis humilis*)

A male and female of this species, in breeding color, were observed May 23, 1911, in Quiver Marshes over what appeared to be a freshly excavated nest in water 18 inches deep. They would occasionally swim a short distance off, but always returned to the same place.

Rather late spawning was indicated in 1910 by the taking, July 7, at the head of Liverpool Lake, of males in full color and females heavy with eggs.

*Called goggle-eye at Havana.

Blue-gill Sunfish (*Lepomis pallidus*)

We found more than fifty nests of this species May 16, 1911, on the west side of Deep Slough, among live willow timber, in water 1 foot to 18 inches deep. The nests were chiefly bunched about the bases of the willows, in some cases as many as a dozen about one tree, all in the shade, and many of them only 2 to 3 feet apart. This fish seems particular to select about the same sort of situation for all its nests,—a rather hard bottom of sand and mud, with little vegetation, but with some fine dead drift, grass, twigs, etc. The nests are 8 to 12 inches in diameter, usually quite round, and the excavation of the bottom soil is always well marked—usually to a depth of half an inch or an inch. All contained eggs nearly ready to hatch or newly hatched fry. The date of spawning was probably between May 1 and 5. The males are much more shy than males of the warmouth bass, but they can easily be seen and identified on nests by approaching quietly. Eggs taken to the laboratory hatched May 17, and by May 22 the yolk sac was wholly absorbed and the fry were swimming free in the aquarium.

May 22, 1911, we found twelve nests in Lynch Slough in similar situations, containing fry apparently 4 to 6 days old. May 26, 1911, we found about three dozen nests at the head of Liverpool Lake, along the west shore, in water 3 feet deep, offshore and outside of the "moss" zone, wholly unprotected by timber or vegetation. Some contained fresh-laid eggs, and others were just built or still unfinished, the progress of nest-building roiling the water in many places. Late-spawning bluegills built nests along the east shore of the Illinois River, less than a rod from the Biological Station, during the second week in August, 1911.

Examination of market specimens and catches from our own nets furnished the following records bearing on breeding dates during the seasons of 1910 and 1911:

May 19, 1910, one female with eggs running taken in Lynch Slough. May 23 to 26, 1910, large numbers of females taken in trammel-net in Deep and Lynch sloughs; eggs maturing, but none near ripe. June 30, 1910, females not yet having spawned taken in Quiver Marshes, though condition of market specimens indicated that spawning was finished before June 10, except for scattered stragglers. May 24, 1911, though nesting had been going on actively for about two weeks, a good many females could be found in the markets with ovaries still hard. Between May 27 and June 3, 1911, several fishermen reported that many females squirted eggs

over nets as these were lifted. June 3, 1911, many females with eggs running, were seen in markets.

Pumpkinseed Sunfish (*Eupomotis gibbosus*)

A ripe female pumpkinseed was taken in the "Flag Pond", south of Lynch Slough May 23, 1910. Eggs could be squeezed out in clouds, and adhered to the glass sides of the aquarium. In Lynch Slough, May 22, 1911, a male and female in high color were seen together over a round opening on the bottom, among moss in 2 feet of water. They went away and came back several times while we watched. Examination of the bottom of the nest showed that no eggs had yet been deposited.

Large-mouth Black Bass (*Micropterus salmoides*)

Between April 26 and May 4, 1911, more than thirty nests of this species were found in an area of about twenty-five acres in the northeast end of Danhole's field. Most of the nests were in 10 to 15 inches of water, but a few were found in water 2 feet deep, and some were in water as shallow as 6 inches. This 25-acre area is thickly grown up with flag and smartweed, among which is some bog-rush and a good deal of filamentous algæ (*Cladophora*). The nests are 12 to 18 inches across, usually nearly round, and well excavated, in most cases more than two inches at the center, and the bottom of most nests is at least partly formed of exposed grass roots, to which many of the eggs adhered. Hatching went on continuously in these nests between April 29 and May 5, under a water temperature of 60° to 65° Fahr. If we assume an incubation period of about fifteen days, the dates of spawning lay between April 15 and 20, when water temperatures stood between 58° and 60°. Eggs hatched in the laboratory April 28 had the yolk sac absorbed by the evening of May 1. The number of eggs in a nest seems to run usually between 2000 and 3000, though in a few cases the number was considerably higher. The males guarding the nests were as a rule under two pounds in weight. In most of the nests the percentage of fungused eggs was low, in some cases hardly more than five per cent. A few nests were found in which nearly all the eggs were fungused. One nest, which we boxed over with a cheese-cloth fry-retainer, contained more than a thousand active fry 3/16 inch long when we visited it May 6. The males are very timid, and usually dart away like a flash before one can even get the nest well in sight; but by using the greatest care to approach quietly we

were able in a few cases to get a good observation of the male over the nest, guarding the eggs.

Other observations on nesting bass in the vicinity of Havana, between May 3 and May 18, 1911, were made at places and dates as follows:

Head of Flag Lake, May 3-6, ten nests, one with eggs near hatching, others with eggs mostly fungused. Weed Prairie, May 4, one nest; eggs well advanced; male seen on nest. West shore of Thompson's Lake, ¼ mile above Warner's Cut, May 16, two nests containing newly hatched fry; 2-lb. male seen guarding one nest. Weed Prairie, May 5-17, twelve nests. Samples of eggs, about 200 each from several of these Weed Prairie nests, hatched with a loss of not more than five per cent. from fungus. These nests were in 2½ to 3 feet of water—considerably deeper than that in the breeding grounds at the head of Danhole's field (usually 10 to 15 in.)—and contained a moderate quantity of living smartweed and algæ. Eggs in most of the nests in Weed Prairie had hatched by May 17, though one nest found on this date contained eggs spawned hardly more than 24 hours.

Observations on advanced fry and fingerlings were made on various dates between May 17 and June 16, 1911, as follows:*

Weed Prairie, May 17, 1911, one school of more than 1000, three weeks old, largest nearly ½ inch long; one school of more than 2000, 24 days old; one school of more than 5000, 21 days old. Fry between two and three weeks old swim in very close schools, in some cases suggesting a swarm of bees. Their movement is very leisurely; it is in fact almost impossible to stampede them. The level kept is considerably below the surface, usually about two-thirds of the way up from the bottom. Most of these schools were found along the margins of the weed-filled breeding grounds—on which the water is now rapidly falling—within easy reach of moderately deep water. Weed Prairie, May 18, 1911, two schools, aggregating about 6000, 3½ weeks old. Lynch Slough, May 22, 1911, one school, several thousand, about 35 days old. These probably hatched before the end of the first week in April. Riley Smith's Marsh, May 23, 1911, several schools, 3 to 5 weeks old, at edges of marsh, in easy reach of

*In these notes all estimates of the age of fry are based on comparison with Reighard—Bull. Mich. Fish Comm., No. 7, in Sixteenth Report of State Board of Fish Commissioners.

creek and lake. Dierker Lake, May 25, 1911, four schools, 1000 each or less, 4 weeks old. The water here was very dirty. The small size of the schools may be due to fungusing of the eggs in the nests. Crabtree dredge-ditch, June 10, 1911, young bass are still in schools, but easily scattered; length 1½ to 2 inches. Head of Quiver Lake, June 16, 1911, scattered fry, no longer in schools; length 1½ to 2½ inches. A good many fry at this age seem to seek the protection afforded by the numerous schools of golden shiners (*Abramis*).

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STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

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BIOLOGICAL AND EMBRYOLOGICAL STUDIES ON FORMICIDÆ

BY

MAURICE COLE TANQUARY, A.M.

ARTICLE IX.—*Biological and Embryological Studies on the Formicidæ.** By M. C. TANQUARY.

I. THE LIFE HISTORY OF THE CORN-FIELD ANT, *Lasius niger* var. *americanus* Emery

Although the common corn-field ant, *Lasius niger* var. *americanus* Emery, is said to be the most abundant of all North American insects, its complete life history has never been worked out. The most that we have on the subject is given in Bulletin 131 of the Illinois Experiment Station by Forbes. He there reports that in four cases the first eggs from young queens were obtained May 8, 9, 10, and 15; that the egg periods were 16, 17, 19, and 23 days; that the pupal stage averaged about 18 days; and that the total number of young produced by a single female in the first year was in three cases 8, 9, and 19 workers. The more extensive data which I have been able to obtain correspond in great measure to those just given.

METHODS

The method followed in this life history study consisted (1) in making observations in the field at all times of the year, (2) in making daily observations on young fertilized and isolated females through one season, (3) in isolating old queens from large nests and getting counts of the eggs they laid, and (4) in keeping large colonies in Fielde nests under daily observation. These young fertilized females were obtained in the fall just after they had descended from their nuptial flight, or after they had formed their cells; or they were taken from their cells in the spring before they had begun to lay eggs. They were kept for the most part in Fielde nests of the ordinary type, or in some cases in Barth nests. The latter are more satisfactory for keeping the ants under natural conditions, but with them one can not make as accurate observations regarding the exact number of eggs and young.

NUPTIAL FLIGHTS

The nuptial flights of *Lasius americanus* usually occur from August to September. The date of a flight mentioned by Forbes is September 14. The earliest date for which I have positive evidence of a flight is September 5. I have noticed, however, in a summer's

*Contributions from the Entomological Laboratories of the University of Illinois, No. 34.

collecting, that during August the percentage of nests containing winged forms decreases, so that it is very probable that the flights begin during that month in this latitude. September 5, 1910, I found a large number of young dealated females of *Lasius niger americanus* crawling on the ground in a park in Boston, Mass. This was about five o'clock in the evening. They had all removed their wings, and were crawling around in search of a place to burrow. A number were already beginning their burrows. At one place I saw six beginning to burrow in the same place. There were also many males flying in the air or crawling about, but I saw no couples *in copula*. The same afternoon I found five young dealated queens of *L. latipes* Walsh, a number of winged and dealated females of *Solenopsis molesta* Say, also a few dead males of *Formica fusca* var. *subsericea* Say. This fact indicates that weather conditions probably determine to a large extent the time of a flight. There had been a heavy rain the day before, but on that day it was clear and very warm. The following day, September 6, with the same weather conditions, I found a large number of males and winged females of *Cremastogaster lineolata* Say crawling about on the walks, and two days later I saw a large number of *Solenopsis molesta* flying, many of them *in copula*. September 19, 1910, and on almost every day for the next ten days, I caught winged females of *Lasius niger americanus* flying or saw the young queens crawling over the ground. On the evening of October 4, I found five winged and sixteen dealated queens of *L. niger americanus* crawling on the ground, one dealated queen October 11, and one October 18. The fact that dealated queens of this species are found crawling about is evidence that there has been a flight, since these queens begin to burrow immediately after descending from their flight and do not come to the surface again.

The dates upon which I have actually witnessed the flights of *L. americanus* from the nest are September 9, September 20, and September 18. All the flights of this species I have noticed have been between 3 p. m. and 6 p. m. The best observations were obtained from the one of September 20. In this case the entrance of a large nest was near the edge of a cement walk. At 4:30 p. m. my attention was called to the fact that a very large number of ants were crawling over the walk and grass near the opening. Closer examination showed that there were many males, winged females, and workers there, all running about excitedly, and that every few minutes a male or female rose from the blades of grass or the walk and flew away. They did not all fly away in the same direction, but seemed to take whatever

course they were headed for. I did not see any pairs *in copula* either in the air or on the ground. In fact, I have never found a pair of this species *in copula,* and think it quite likely that fertilization takes place in the nest some time before the flight.

FOUNDING OF THE COLONY

Several methods of founding a colony are now generally recognized. These methods have been designated by Wheeler ('06, pp. 34, 35) as the typical, the redundant, and the defective.

In the first case the female after descending from her nuptial flight, removes her wings and burrows into the ground or enters a cavity beneath the bark of a log, or the like, where she forms a small cell and begins to lay eggs or passes the winter and then begins to lay eggs. When these hatch she feeds the larvæ from her own secretions.

In the second case the female in addition to doing all that is required in the typical method, also cultivates certain fungi for herself and her brood.

The defective method Wheeler has subdivided into (1) temporary social parasitism, (2) permanent social parasitism, and (3) dulosis, or slavery. In temporary social parasitism the female enters a queenless colony of some other species and becomes adopted, thus getting the alien ants to rear her first brood. These alien ants naturally die off in the course of time, leaving a pure colony of the same species as the queen.

It is very well known that the first method mentioned is the one usually employed by *L. niger americanus,* and it is generally believed to be the only one employed. One may find solitary females in their cells a few inches beneath the surface of the ground in October and November; and may also find late in the summer or in the spring a colony consisting of a queen and a few minim workers and larvæ, the product of one year's growth.

November 18 I found in a corn field infested with *Aphis maidiradicis* Forbes, six separate cells, each containing a solitary female. There were no eggs or young. The cells were only a few inches beneath the surface, three of them being beneath clods of earth. On April 5, I found a lone queen in her cell a few inches beneath the surface in a stalk-field, without eggs or young. Eggs may be laid, however, in the fall. On September 5, I picked up thirty-six dealated females that had just descended from their nuptial flights and placed them together in a large Fielde nest. Within the

next few days between 150 and 200 eggs were laid. These eggs, however, all spoiled, as though they were not properly taken care of. This has been the case in every other instance in which I have had young queens lay eggs in the fall. This, however, may be due to artificial conditions. The queens lay again in spring, about May, the exact time depending upon weather conditions. The one I collected April 5 and kept under natural conditions laid her first egg May 16. Some of the queens which I kept in a warm room during the winter began to lay as early as the first of March. The number of young produced the first season is very small as compared with the number of eggs laid by the queen. In all my nests containing single queens, the queen was more or less given to eating her own eggs. Some ate only a few, while others ate nearly all. This was not due to lack of food, as I had provided food for them. The fact that all the queens ate their eggs to some extent, and the fact that the number of young produced under natural conditions is so much less than the number of eggs laid, lead me to believe that the queen under normal conditions eats a certain proportion of her eggs. Possibly this habit enables her to get the proper kind of food for her larvæ.

The detailed history of a few first-year colonies follows.

COLONY *27b*

This queen was taken November 20, from a cell which she had established a few inches beneath the surface of the ground in a corn field. The room in which she was kept during the winter was a greenhouse, which became quite warm (70°—80° F.) at times; though at other times the temperature fell below freezing. Keeping her in a warm room accounts for the fact that she began laying so early. Aside from the fact that egg-laying began much earlier, the history of this colony is not different from that of others in which the queens were kept under natural conditions, so that these results may be taken as typical.

The first egg was laid February 17. It disappeared February 22 (probably eaten) and no other was laid until February 27.

COLONY 27*b**

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
Feb. 27....	1	1						
" 28....	1	2						
Mar. 4....	1	3						
" 5....	3	6						
" 6....	1	7						
" 8....	2	9						
" 10....	2	11						
" 11....	3	14						
" 12....	1	15						
" 16....	2	17						
" 17....	4	21						
" 18....	1	22						
" 21....	2	24						
" 24....	1	25						
" 28....	1	26						
" 29....	2	28						
" 30....	2	30						
Apr. 1....	2	32						
" 3....	1	33						
" 5....	1	34						
" 6....	6	40						
" 8....	2	42						
" 12....	4	46						
" 13....	1*	45						
" 14....	3	48						
" 15....	0	47	1	1				
" 16....	2	48	1	2				
" 17....	5	47	6	8				
" 18....	3*	41	3	11				
" 19....	1*	32	8	19				
" 22....	0	29	3	22				
" 23....	2	30	1	23				
" 24....	5*	21	4	27				
" 25....	7	28	0	27				
" 26....	2	30	0	27				
" 27....	6*	24	0	27				
" 28....	1	25	1*	26				
" 29....	5*	20	5*	21				
" 30....	4*	16	0	21				

*In this table the asterisk signifies missing; the dagger, accidentally injured or destroyed; and the double dagger, dead.

COLONY 27*b*—*Continued*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
May 1....	0	14	2	22	1	1		
" 3....	3*	11	0	22	0	1		
" 4....	0	11	0	22	0	1		
" 5....	3	14	3*	18	1	2		
" 6....	0	9	5	22	1	3		
" 7....	1*	7	1	22	1	4		
" 8....	0	7	1*	20	1	5		
" 9....	1	8	0	19	1	6		
" 10....	2	9	1	17	3	9		
" 11....	1	8	2	19	0	9		
" 12....	1	9	0	18	1	10		
" 13....	6	15	0	18	0	10		
" 14....	0	15	0	18	0	10		
" 16....	4	19	0	18	0	10		
" 17....	3	22	0	18	0	10		
" 18....	5*	17	0	18	0	10		
" 19....	1*	16	0	18	0	10		
" 20....	0	16	0	17	1	11		
" 21....	1*	15	1*	15	1	12		
" 22....	1	15	1	16	0	12		
" 23....	2	16	1	16	1	12	1	1
" 24....	2*	14	0	16	0	12	0	1
" 25....	1	15	0	16	0	12	0	1
" 26....	1	16	1*	15	0	12	0	1
" 27....	3	19	0	15	0	12	0	1
" 28....	4	22	1	14	2	13	1	2
" 29....	10	32	4*	10	0	12	1	3
" 30....	4*	28	0	10	0	11	1	4
" 31....	2*	26	0	10	0	11	0	4
June 1....	0	26	0	10	0	10	1	5
" 2....	4	30	2*	8	1*	8	1	6
" 4....	6	34	2	10	1*	5	2	8
" 5....	0	33	1	11	0	4	1	9
" 6....	3	36	0	11	0	4	0	9
" 7....	0	36	2*	9	0	4	1†	8
" 8....	0	36	0	9	0	4	1‡	7
" 9....	6*	30	2*	7	0	4	0	7
" 10....	5	35	1*	6	0	4	0	7
" 11....	12	46	1	6	1	5	0	7
" 12....	4*	42	0	4	2	7	0	7
" 13....	3	42	3	6	1	8	0	7

COLONY 27*b*—*Continued*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
June 18§...	14	56	1*	2	3	9	2	9
" 19....	5	61	0	2	0	8	1	10
" 20....	0	59	2	4	0	8	0	10
" 21....	5	63	1	5	0	8	0	10
" 23....	4	64	3	8	0	8	0	10
" 24....	8*	52	4	12	0	8	0	10
" 25....	2	54	0	12	0	8	0	10
" 26....	2	56	2*	9	1	9	0	10
" 27....	7*	46	3	12	0	9	0	10
" 28....	3	47	2	14	0	9	0	10
" 29....	0	47	0	14	0	7	2	12
" 30....	14*	30	3	17	0	5	2	14
July 2....	10*	20	0	17	1*	4	0	14
" 4....	0	19	1	18	0	2	2	16
" 5....	4*	15	0	18	0	2	0	16
" 6....	0	14	1	18	1	3	0	16
" 7....	0	13	1	18	1	4	0	16
" 8....	0	13	0	18	0	3	1	17
" 9....	0	10	3	21	0	3	0	17
" 10....	2	12	0	20	1	4	0	17
" 11....	2	14	0	20	0	4	1‡	16
" 12....	0	14	0	20	0	4	0	16
" 13....	0	14	4*	16	0	4	0	16
" 14....	3	17	0	16	0	4	0	16
" 15....	0	17	0	16	0	4	0	16
" 16....	1	18	7*	9	0	3	1	17
" 17....	4	22	0	9	0	3	0	17
" 18....	0	22	0	9	0	3	0	17
" 19....	8	30	0	8	1	4	0	17
" 20....	0	30	0	8	0	4	0	17
" 21....	0	30	0	8	0	4	0	17
" 22....	8	38	4*	3	1	5	0	17
" 23....	0	38	0	3	0	5	0	17
" 24....	0	38	0	3	0	5	0	17
" 25....	2	40	0	3	0	5	0	17
" 26....	0	40	0	3	0	3	2	19
" 27....	0	40	0	3	0	3	0	19
" 28....	0	40	0	3	0	3	0	19
" 29....	0	39	1	3	1	3	1	20
" 30....	0	39	0	3	0	3	0	20
" 31....	0	38	1	4	0	3	0	20

§June 14-17, no examination made.

COLONY 27*b*—*Concluded*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
Aug. 1....	0	38	0	4	0	3	0	20
" 3....	0	38	0	3	1	4	0	20
" 4....	0	38	0	3	0	3	1	21
" 5....	0	38	0	2	1	4	0	21
" 6....	0	38	0	2	0	4	0	21
" 7....	0	38	0	2	0	4	0	21
" 8....	0	38	0	2	0	3	1	22
" 9....	0	38	0	2	0	3	0	22
" 10....	8*	30	0	2	0	3	0	22
" 11....	0	30	0	2	0	3	0	22
" 12....	1	31	0	2	0	3	0	22
" 14....	3*	28	1*	1	0	2	1	23
" 15....	0	28	0	1	0	2	0	23
" 16....	0	28	0	1	1*	1	0	23
" 17....	0	28	0	1	0	1	0	23
" 18....	2	30	0	1	0	1	0	23
" 19....	0	30	0	1	0	1	0	23
" 23....	0	30	0	1	0	0	1	24
" 25....	9	38	1	2	0	0	0	24
Sept. 1....	0	38	0	2	0	0	0	24

I was compelled to neglect the colony for a time. September 25, the nest contained 16 workers and 12 larvæ (the latter in poor condition); September 28, 5 eggs and 16 workers; and October 5, 2 larvæ and 16 workers.

This colony, consisting of the queen, 2 larvæ, and 16 workers, remained the same up to November 17, when I found one of the workers dead. By November 16 the weather had become much colder, and during the rest of the winter the ants remained in a dormant condition. Owing to the fact that conditions were not just right, or that the ants were not in the best physiological condition to enter hibernation, the latter did not survive the winter.

An examination of the above data shows that up to September 1, this queen had laid 222 eggs; that but 27 adults were reared from them; that but 3 adults died, one because I had injured it; that 4 individuals died or disappeared in the pupal stage, 42 in the larval stage, and 109 in the egg stage. Whatever may have been the cause of the dying of the larvæ and pupæ, I am sure that at least a large percentage of the eggs was eaten, because many times I found eggs in the nest that had been partly eaten.

Assuming that the first larvæ hatched from the first eggs, we have the following egg periods for the first 27 larvæ:

For	the	first	egg, 47 days	For	the	next 2	eggs, 34 days
"	"	next	(1), 47 days	"	"	"	(2), 33 days
"	"	"	(1), 44 days	"	"	"	(2), 36 days
"	"	"	(3), 43 days	"	"	"	(1), 35 days
"	"	"	(1), 42 days	"	"	"	(1), 33 days
"	"	"	(1), 40 days	"	"	"	(1), 34 days
"	"	"	(1), 41 days	"	"	"	(1), 31 days
"	"	"	(5), 39 days	"	"	"	(1), 27 days
"	"	"	(1), 38 days	"	"	"	(1), 26 days

On the same basis we find that the length of the larval stages for the first 15 larvæ are as follows:

For	the	first	larva, 16 days	For	the	next	(1), 22 days
"	"	next	(1), 19 "	"	"	"	(1), 24 "
"	"	"	(1), 19 "	"	"	"	(1), 32 "
"	"	"	(1), 20 "	"	"	"	(1), 32 "
"	"	"	(1), 21 "	"	"	"	(1), 34 "
"	"	"	(1), 22 "	"	"	"	(2), 39 "
"	"	"	(2), 23 "				

For the next few that transformed the time was still longer, but could not be determined exactly since some of the larvæ disappeared.

The pupal stages for the first 15 adults are as follows:

For	the	first	(1), 22 days	For	the	next	(1), 29 days
"	"	next	(3), 23 "	"	"	"	(2), 29 "
"	"	"	(2), 24 "	"	"	"	(1), 37 "
"	"	"	(1), 25 "	"	"	"	(1), 32 "
"	"	"	(1), 26 "	"	"	"	(1), 33 "
"	"	"	(1), 37 "				

COLONY 27*a**

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
Mar. 1....	1	1						
" 3....	3	4						
" 6....	3	7						
" 7....	6	13						

*In this table the asterisk signifies missing; and the dagger, accidentally injured or destroyed.

COLONY 27*a*—*Continued*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
Mar. 10....	5	18						
" 12....	2	20						
" 14....	5*	15						
" 16....	4	19						
" 21....	3	22						
" 23....	3	25						
" 24....	2	27						
" 25....	1	28						
" 26....	4	32						
" 28....	3	35						
" 29....	4	39						
Apr. 1....	1	40						
" 5....	2	42						
" 6....	5†	47						
" 6....	5*	42						
" 7....	6*	36						
" 8....	6	42						
" 9....	6	48						
" 10....	5	53						
" 11....	3*	50						
" 12....	11	61						
" 13....	8*	53						
" 14....	1*	52						
" 16....	7	59						
" 17....	4	63						
" 18....	6	66	3	3				
" 19....	0	63	3	6				
" 20....	5	68	0	6				
" 21....	5	71	2	8				
" 24....	2*	69	0	8				
" 25....	9	77	1	9				
" 26....	4	81	0	9				
" 27....	4*	77	0	9				
" 28....	0	77	1*	8				
" 29....	5	82	0	8				
" 30....	15*	67	1*	7				
May 1....	8	75	1*	6				
" 3....	0	74	1	7				
" 5....	10	84	0	7				
" 6....	11*	70	3	10				
" 7....	1	70	1	11				
" 8....	0	68	2	13				

COLONY 27*a*—*Continued*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
May 9....	1	68	1	13	1	1		
" 10....	5*	61	2	14	1	2		
" 11....	7	68	2*	12	0	2		
" 12....	5*	62	1	13	0	2		
" 13....	1	62	1	14	0	2		
" 14....	5	64	3	17	0	2		
" 15....	0	61	3	19	1	3		
" 16....	3*	58	0	19	0	3		
" 17....	8	66	0	19	0	3		
" 18....	7*	53	6	25	0	3		
" 19....	1*	52	1*	24	1*	2		
" 20....	4*	48	0	23	1	3		
" 21....	6*	42	0	22	1	4		
" 22....	1*	37	4	25	1	5		
" 23....	2*	34	1	26	0	5		
" 24....	3	33	4	30	0	5		
" 25....	3*	30	4*	26	0	5		
" 26....	2	32	0	25	1	6		
" 27....	2	33	1	25	1	7		
" 28....	1*	32	0	25	0	7		
" 29....	4*	28	0	25	2*	5		
" 30....	0	28	0	24	1	6		
" 31....	0	28	1*	22	1	7		
June 1....	0	28	0	22	0	7		
" 2....	4	30	2	23	1	8		
" 4....	0	30	0	23	0	8		
" 5....	3	33	2*	21	0	8		
" 6....	2	35	2*	19	0	8		
" 7....	8	42	1	19	1	9		
" 8....	1	43	1*	17	1	10		
" 9....	2*	41	3*	14	0	10		
" 10....	7	48	0	14	0	10		
" 11....	0	48	0	14	0	10		
" 12....	1*	47	0	14	0	10		
" 13....	1	47	1	15	0	10		
" 18....	30*	17	0	14	1	7	4	4
" 19....	0	17	3*	10	1	8	1*	3
" 20....	2	17	2	12	3*	5	0	3
" 21....	4*	13	1*	11	1*	4	1*	2
" 23....	12*	1	1*	8	2	4	2	4
" 24....	6	7	0	8	0	3	1	5
" 25....	1	8	0	8	1*	2	0	5

COLONY 27*a*—*Concluded*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
June 26....	1*	7	0	7	1	3	0	5
" 27....	0	7	0	7	0	3	0	5
" 28....	7	14	0	6	1	4	1*	4
" 29....	4	18	0	5	1	5	0	4
" 30....	2	20	1*	4	0	5	0	4
July 2....	4	24	0	3	1	6	0	4
" 4....	1*	23	0	3	1*	5	2*	2
" 5....	0	23	0	3	0	5	0	2
" 6....	0	23	0	3	0	4	1	3
" 8....	7*	16	0	3	0	4	0	3
" 9....	1	17	0	3	0	4	0	3
" 10....	10	27	1*	1	1	5	0	3
" 11....	0	27	0	1	0	5	0	3
" 12....	0	27	0	1	0	5	0	3
" 13....	8	35	0	1	0	5	0	3
" 14....	14	49	0	1	0	5	0	3
" 15....	0	49	0	1	1*	4	0	3
" 16....	4	53	0	1	1*	2	1	4
" 17....	0	53	0	1	0	1	1	5
" 18....	5	58	0	1	0	1	1*	4
" 19....	2	60	0	1	0	1	0	4
" 20....	10*	50	0	1	0	1	0	4
" 22....	0	50	1*	0	0	0	1	5
" 30....	4	52	2	2	0	0	0	5
Aug. 1....	7*	45	0	2	0	0	0	5
" 2....	5*	40	0	2	0	0	0	5
" 3....	4*	36	0	2	0	0	0	5
" 5....	6*	30	2*	0	0	0	0	5
" 7....	6*	24	0	0	0	0	0	5
" 9....	4	28	0	0	0	0	0	5
" 12....	2	30	0	0	0	0	0	5
" 14....	10	40	0	0	0	0	0	5
" 18....	4*	36	0	0	0	0	0	5
" 19....	6*	30	0	0	0	0	0	5
" 20....	7*	23	0	0	0	0	0	5
" 21....	3*	20	0	0	0	0	0	5
" 22....	2	22	0	0	0	0	1*	4
" 25....	5	26	1	1	0	0	0	4
" 27....	2*	24	0	1	0	0	0	4
" 28....	6	30	1*	0	0	0	0	4
Sept. 3....	8*	22	0	0	0	0	0	4

I was obliged to neglect the colony for several days and as a result it perished.

This queen laid a total of 302 eggs, from which but 11 adults were reared; 11 individuals disappeared in the pupal stage, 30 in the larval stage, and 228 in the egg stage. Not all the young that disappeared in this case were eaten by the queen, as it sometimes happened that they were placed in the condensed moisture around the sponge and spoiled.

It is not possible to get the exact length of the stages in this colony, since some of the eggs disappeared before any had hatched, some of the larvæ disappeared before any had pupated, and some of the pupæ disappeared before any adults emerged. However, if we assume that the first 6 eggs passed through all the stages and became adults, the stages would be as follows:

For the first egg, 48 days
For the next 2 eggs, 46 days
For the first larva, 21 days
" " next " 22 "
" " " " 27 "
" " " " 31 "
" " " " 32 "
" " " " 33 "

For the next egg, 47 days
For the next 2 eggs, 44 days
For the first pupa, 40 days
" " next " 39 "
" " " " 34 "
" " " " 29 "
" " " " 33 "
" " " " 32 "

COLONY 30

This queen was taken as a solitary female from her cell in a corn field by G. E. Sanders on May 7. At first I had her in the same nest with another queen taken the same day On May 18, 3 eggs appeared in the nest, and on May 19, 2 more. I then removed one queen and the 5 eggs. The remaining queen laid no eggs until May 26.

COLONY 30*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
May 26....	6	6						
" 27....	1	7						
" 28....	1	8						
" 29....	1	9						
" 30....	5	14						
" 31....	2	16						

*In this table as heretofore, the asterisk signifies missing; the dagger, injured or destroyed.

COLONY 30—*Continued*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
June 1....	0	16						
" 4....	2	18§						
" 5....	3	18						
" 6....	1*	17						
" 7....	0	17						
" 8....	4	21						
" 10....	0	21						
" 12....	6	27						
" 13....	8	35						
" 18....	7	42						
" 19....	1	42	1	1				
" 20....	5	44	3	4				
" 21....	2	43	3	7				
" 23....	0	42	1	8				
" 24....	2	41	3	11				
" 25....	6	44	3	14				
" 26....	4*	40	0	14				
" 27....	2	42	1‡	13				
" 29....	0	40	2	15				
" 30....	1*	37	2	17				
July 2....	3*	30	4	21				
" 4....	4*	24	2	23				
" 5....	0	21	3	26				
" 6....	3*	17	1	27				
" 8....	4	21	2*	25				
" 9....	3	23	1	26				
" 10....	0	23	0	26				
" 11....	3*	20	0	25	1	1		
" 12....	4	24	0	25	0	1		
" 13....	0	24	0	25	0	1		
" 14....	11	34	1	26	0	1		
" 15....	0	34	0	25	1	2		
" 16....	0	34	0	25	0	2		
" 17....	2	34	2	27	0	2		
" 18....	0	34	0	26	1	3		
" 19....	0	32	2	28	0	3		
" 20....	2*	30	0	28	0	3		
" 21....	4*	26	0	28	0	3		
" 22....	0	26	0	28	0	3		
" 23....	0	26	0	25	3	6		

§I destroyed 3, leaving 15.

COLONY 30—*Concluded*

Date	Eggs	Total	Larvæ	Total	Pupæ	Total	Adults	Total
" 24....	1*	25	1*	23	1	7		
" 25....	0	25	0	23	0	7		
" 26....	0	24	1	24	0	7		
" 29....	9	32	1	24	1	8		
Aug. 1....	0	32	0	24	0	7	1	1
" 3....	8*	24	2*	22	0	7	0	1
" 4....	0	24	0	22	1*	5	1	2
" 5....	0	24	0	22	0	5	0	2
" 6....	0	24	0	21	1	6	0	2
" 7....	0	24	0	20	1	6	1	3
" 9....	0	24	0	19	1	7	0	3
" 10....	4*	20	2*	17	1*	5	1	4
" 11....	0	20	0	17	0	3	2	6
" 12....	0	20	0	17	0	2	1	7
" 14....	0	20	0	16	1	3	0	7
" 16....	0	20	0	15	1	4	0	7
" 17....	3*	17	3*	12	0	3	1	8
" 13....	2*	15	0	11	1	4	1*	7
" 19....	0	15	0	11	0	4	0	7
" 20....	0	15	0	10	1	5	0	7
" 25....	7	22	1*	9	0	5	0	7
" 27....	0	22	1*	8	0	5	0	7
" 30....	6	28	2*	5	1	6	0	7
Sept. 3....	0	28	0	5	0	6	0	7
" 21....	14*	14	3*	2	3*	1	2	9
" 28....	4*	10	0	2	0	1	0	9
Oct. 3....	0	8	2	4	0	1	0	9
" 7....	0	8	0	4	0	0	1	10

There was no further development of this colony, as the weather became too cool. Several adults died. December 2, I transferred the colony to a warm room. December 20 the queen began laying again, and by January 10 she had laid 17 eggs. January 19 the queen died and the colony was discarded.

Assuming that the first 6 eggs developed into the first 6 adults, the lengths of the various stages are as follows:

For first egg, 24 days; for next 3 eggs, 25 days; and for next 2, 26 days.

For first larva, 22 days; for next one, 25 days; for next one, 28 days; for next one, 33 days; and for next (2 larvæ), 32 days.

For first pupa, 21 days; for next (2 pupæ), 20 days; for next pupa, 18 days; and for next (2 pupæ), 19 days.

This gives for the first 6 eggs an average time of 25 days; for the first 6 larvæ, 28.6 days; for the first 6 pupæ, 19.5 days.

In colony *27b* the average time for the first 6 eggs is 44.5 days; for the first 6 larvæ, 19.5 days; and for the first 6 pupæ, 23 days. In colony *27a* the average time for the first 6 eggs is 46 days; for the first 6 larvæ, 28 days; and for the first 6 pupæ, 34.5 days.

The queen in colony 30, laid a total of 110 eggs, from which 11 adults were reared. Five individuals disappeared in the pupal stage, 18 in the larval stage, and 64 in the egg stage.

COLONY 28

April 5, I took a solitary queen from her cell in a corn field and placed her in a Fielde nest under normal temperature conditions. She began to lay May 16. By August 25, when she died, she had laid 54 eggs, from which but one adult was reared. Twenty-four individuals disappeared in the egg stage, 27 in the larval stage, and one in the pupal stage. Forty-eight of the 54 eggs were laid between May 16 and June 2. After that date the queen did not seem to do well. The lengths of the egg periods for the first 6 eggs are as follows: for the first (1), 25 days; for the next (1), 24 days; and for the next (4), 25 days.

Because of the fact that this queen did not take good care of the young, most of them perished and I could not get the lengths of the stages.

COLONY 18

This queen was carried over winter in a Fielde nest in a warm greenhouse. She began laying April 10. By June 27, when she died, she had laid 93 eggs. But 3 pupæ were reared from these, 29 disappeared in the larval stage, and 61 in the egg stage. The lengths of the egg stages for the first 6 eggs are as follows: for the first 2 eggs, 26 days; for the next 4 eggs, 23 days.

This gives an average of 24 days as the length of the egg period for the first 6 eggs. No eggs disappeared in this nest until after the larvæ appeared, so the stages here may be taken as exact.

COLONY 18*c*

This queen was taken in the fall and carried over winter in a warm greenhouse, but on March 25, before she had laid any eggs, was transferred to a room where the temperature was normal. She

began laying April 27, and by June 10, when she died, had laid 45 eggs; but they kept disappearing from time to time, and none of them hatched.

COLONY 18*d*

This queen was taken at the same time as the one in colony 18*c*, and kept under the same conditions. She began laying the same day, April 27, and by July 31, when she died, she had laid 114 eggs, but for the same reason as above, none of them hatched.

COLONY 26*a*

This queen was kept over winter in a warm greenhouse. She began laying February 27, and by September 3 had laid 140 eggs, from which but two adults were reared. As so many disappeared at different times I could not get the lengths of the various stages.

A large number of the queens which I used for starting colonies lived only a few weeks or months and did not bring any young to maturity, although all laid eggs. Some of them seemed to eat a large percentage of the eggs, while others simply allowed the eggs to spoil. Three other queens may be mentioned. The one in Colony B, No. 1*c*, taken in April and kept under natural conditions, produced 2 workers and 11 larvæ by September 15. The egg period for the first 2 eggs was 24 days. The egg stages for the first 3 larvæ were 21, 24, and 25 days, respectively. The pupal period for the first adult which emerged was 26 days.

In Colony B, No. 1*d*, the queen produced 9 workers by September 7.

Colony B, No. 1*I* was kept under practically normal conditions. The queen was taken about the middle of April and kept with some others until June 24, when I placed her in a Barth nest, made by placing a glass cylinder 3 inches high and 3 inches in diameter inside a cylindrical glass jar 4 inches high and 4 inches in diameter, and filling the space between the cylinder and the jar with moist sand. The top was then covered with a layer of cotton batting, and this was held down by a pane of glass. The queen began to burrow at once, and by June 30 had made a complete cell at the bottom of the sand and had deposited several eggs. In forming her cell the queen had completely closed the burrow by means of which she reached the bottom of the sand. With such a nest it was impossible to take

daily observations as to the number of young, but I have the following notes on the development of the colony:—

August 3, I count 15 cocoons and see a number of eggs and larvæ; Aug. 8, I count 21 cocoons; Aug. 17, three callows have emerged; Aug. 20, there are 5 callows today.

August 25. There are at least 10 callow workers today. They are very active and have excavated a tunnel nearly 6 inches in length around the bottom of the glass jar. They have moved some of the brood about 1½ inches from the original cell of the queen.

August 28. There are 15 callow workers. Very active. Their main tunnel is about 10 inches in length and is started upward. It is half-way to the top of the cylinder.

August 29. They have excavated to the top of the sand.

I did not break up this nest in order to get the exact count, but the approximate count at the end of the season was 15 to 17 workers and 1 larva. No pupæ or eggs.

The seven cases in which the queen succeeded in founding a colony and living through the season are as follows.

Number of colony	Number of workers produced	Total number of eggs
27*b*	11	222
27*a*	27	302
30	11	110
26*a*	2	140
B, No. 1*c*	2	
B, No. 1*d*	9	
B, No. 1*l*	16	

This gives an average of 11 workers produced by a queen in one season, with a maximum of 27. The average number of eggs laid by the queens in the four cases in which I was able to get the entire count, is 193.5. The first-year workers are very small, on account of insufficient nourishment.

The above data show that sexual forms are not produced the first year. It is not at all likely that they are produced the second year because of the very greatly increased amount of nourishment required for producing them. After the second year the average and maximum colonies probably increase very rapidly, as the number of workers is then large enough to provide plenty of nourishment for the queen to lay a much larger number of eggs.

The following data show how much more prolific the queen is when she is well nourished by a large colony:—

July 7, I took the old queen from a large colony of *L. niger americanus* under a stone and brought her to the laboratory. At 10:00 a. m. I placed her in a vial by herself. By 4:00 p. m. she had laid 125 eggs, an average of 31 an hour, or one every two minutes. I removed her from the vial and placed her in a Petri dish with five workers from the same colony.

July 9, 9:00 A. M. Moisture from the sponge had collected in the bottom of the Petri dish, and the queen and workers were nearly drowned. The queen, however, had laid 168 eggs. I placed her in a dry vial. She began laying again at 11:45 and by 2:00 p. m. had laid 48 more eggs. Thus in a little more than two days this queen laid 341 eggs, or more than the average of the total number laid by the four first-year queens in an entire season.

August 13, I took the old queen from a very large colony of *L. niger americanus,* brought her to the laboratory, and placed her in a Petri dish at 5:30. I watched her continuously for 30 minutes, during which time she laid eggs, at fairly regular intervals, at the rate of about one every two minutes. By 6:00 p. m. she had laid 16 eggs. By 11 o'clock the following morning she had laid 166 eggs, an average of 9.5 eggs an hour. Between 11:00 A. M. and 12:00 M. she laid 6 more eggs.

By the beginning of the third year the average colony is so large that, if suitably located, it can furnish sufficient nourishment to cause the queen to produce a much larger number of eggs and also to feed the increased number of larvæ. Such a colony might be sufficiently large for the workers to feed a certain number of the larvæ heavily enough to produce, not workers, but winged females. Some colonies, however, as those that produced but two workers the first year, might be no larger at the end of the second or even at the end of the third year than the more fortunate ones at the end of the first year. Such colonies would probably not produce females until the fourth or fifth year or even later, on the assumption that the difference in the production of workers and females is a difference in nutrition, which I believe to be the case. If a colony containing brood but no queen is supplied with an abundance of food, they will segregate a number of the larvæ, feed them more heavily than the others, and cause them to produce queen larvæ.

HIBERNATION

With the approach of cold weather the ants become inactive and gather together in a few of the main galleries of the nest with their larvæ, occupying at that time a very limited region compared with the large area occupied by their extensive tunnels in the summer time. I have never found anything but queen, workers, and larvæ in the nests in late fall, winter, or early spring. I have never found males or winged females of this species in winter, although it is quite common to find the winged forms of some other species in the nests during the winter. This shows that the winged forms all leave the nests in the summer or autumn. My observations show that the ants are very little, if any, deeper in the soil in winter than in summer. In fact, they seem to use their largest summer tunnels for their winter quarters. The first few days of January, 1909, were very warm. The frost was out of the ground in the open fields so the farmers could plow. January 4, I followed a plow in an old corn-field, and found in the bottom of the furrows a large number of nests of *L. niger americanus* exposed, just as one finds them in the spring and summer. The ground was so cold that the ants were quite stupid and very inactive, and they were huddled together in masses with their larvæ. Such masses could be picked up in places by handfuls, when the ants would very slowly crawl about over one another. They were far too stiff and inactive, however, to have moved with their large bunches of larvæ from the deeper galleries during those few warm days, so they must have been in these same galleries during the previous part of the winter, and would have remained there all the rest of the cold weather. As the ants were warmed by the heat of the hand, or that of the laboratory, they soon became as lively as ever and resumed their normal activities.

Drouth will drive the ants down into the soil much deeper than cold. In very dry weather I have followed their tunnels to a depth of 22 inches, and often in the summer time many of their main galleries are eight to ten inches deep. In the fall of 1909 I marked a number of nests of *L. niger americanus* in an old corn-field, and at various times during the following winter examined one or more of them. I found the ants at the depths one finds them during the summer, that is, from just below the surface to eight and ten inches down. Most of the ants and their larvæ were from four and a half to seven inches down, although I found some not more than two inches below the surface when the ground was frozen to a depth of five and six inches. When the ground was frozen the walls of the

cells were covered with a thin layer of ice, inclosing the ants and their larvæ in an icy cell. These ants on being thawed out became active immediately. In two of these nests I found eggs of the corn-root louse, *Aphis maidiradicis* Forbes. These were in little packets in cells by themselves, not with the larvæ. In the nest containing the largest number of eggs, the cells containing the eggs of the plant-louse were four and a half inches below the surface. By working carefully with a trowel I was able to get the largest packet of eggs out with very little dirt, and on taking them to the laboratory and counting them I found that I had thus separated 894 eggs, and as there were other smaller packets in the nest, there was probably twice that number of aphid eggs in the nest altogether. These eggs had probably been laid by oviparous females which had been carried down into the galleries by the ants. November 10, I found one oviparous female and some eggs in the galleries of a large colony about 5 inches below the surface, although the main galleries of this nest extended downward to a depth of from 12 to 18 inches. In such nests the youngest larvæ were in the deepest portions of the nest, while the larger ones were nearer the surface.

The fact that larvæ are found in the nests during the winter shows that the length of the larval period is variable, depending upon temperature, and also probably upon other factors, as nourishment, moisture, etc. If a colony containing a large number of larvæ all of about the same size be fed heavily, the workers do not feed the larvæ uniformly, but separate a relatively small number from the rest and give them much more nourishment, which causes them to pupate much sooner. Then they separate a few more and feed them in the same way. The latter may have hatched as early as the former, but their larval period is much longer.

In one of my colonies some of the larvæ remained as such for more than a year. This colony was collected November 6, and contained about 300 workers and a large number of larvæ but no queen. I kept them for a while in the greenhouse mentioned above, but about the middle of the winter transferred them to a warm room and fed them heavily. The larvæ began to grow rapidly and on March 2, 25 of them spun cocoons. The next day there were between 75 and 100 cocoons in the nest, and new cocoons were formed every day from that time. It was interesting to see how busy the ants were when so many larvæ were spinning cocoons at once. Every larva, when it was ready to spin a cocoon, was covered with fine pieces torn from the sponge, or other debris, in order to give it something to which to attach its first silken threads. As though to

avoid a useless expenditure of labor, these larvæ were not scattered about indiscriminately, but were mostly placed in one heap consisting of seven or eight layers reaching from the floor to the ceiling of the nest, so that the same pieces of debris would serve for more than one larva. One evening I placed a piece of boiled lean beef, about 1 cm. square and half as thick, in the nest for food. By the next morning it had been torn into shreds, and these had been used by the ants in covering the larvæ. If the larvæ failed to attach their threads the result was naked pupæ. I saw one larva that had accidentally wriggled out of its half-spun cocoon; later it became a naked pupa. When a cocoon was finished the workers removed it from the pile, carefully cleaned off the bits of sponge, meat, etc., and placed it with others in a clean pile. When the adult is ready to emerge the workers remove the cocoon from the pile, bite it open, and help out the young callow. The workers had placed thirty of the larvæ in one pile, and had fed them so heavily that they were forming queen larvæ. By March 10 these were about twice the size of the full-grown worker larvæ. March 15, this nest showed the most distinct grouping of the inhabitants of the nest I have ever seen. There were seven distinct groups. These were (1) the thirty queen larvæ, (2) the buried larvæ spinning cocoons, (3) a small bunch of cocoons with the naked pupæ (there were 15 naked pupæ), (4) all the rest of the cocoons (more than 100), (5) the nearly full-grown larvæ which were feeding heavily (these had their anterior ends pressed against a bit of egg, and with a lens one could see their jaws working as they ate their food), (6) the youngest larvæ, but little larger than the egg, and (7) those larvæ intermediate in size between those of groups 5 and 6. On March 26 the first three adults emerged and the next day seven more. This gives a period of 24 and 25 days for these pupæ. The empty cocoons were carried over to one corner and placed in the waste heap. On April 1, one of the queen larvæ was partly eaten, and from that time these gradually disappeared, one or two a day, until May 5, when the last two were eaten with the exception of one that had spun a cocoon on April 19. During all this time I kept the colony well supplied with food consisting of sugar-water, egg yolk, boiled beef, and insect food such as white grubs, pieces of flies, beetles, etc. On May 5 the queen pupa was taken out of its cocoon, formed on April 19. The following notes show something of the rate and time of deposition of chitin:—

May 10. The queen pupa shows a deposit of chitin at the edge of the mandibles, making a brownish line along the teeth. All the

rest of the surface is white excepting the compound eyes and ocelli, which are already dark,—the compound eyes very dark, and the ocelli a light brown.

May 11. The pupa has acquired a light brown tint all over. The teeth of the mandibles are darker and the brown is beginning to go back over the rest of the mandible.

May 12. The general color of the body is a little darker.

May 13. Still darker.

May 14. The queen has emerged.

This gives a period of 25 days for the queen pupa, the same as that for the first few worker pupæ. This female never seemed to be healthy, and died on June 30.

There were no more larvæ produced by this colony. The rest of the larvæ continued to pupate and adults continued to emerge until July 7. On that date there were no more cocoons in the nest, and none of the larvæ which were in the nest over winter. All the adults which emerged were workers except the one female. There were no males.

April 4, I noticed for the first time a bunch of 40 or 50 eggs. These were of course worker eggs, as there was no queen in the nest. By May 1 there were several hundred eggs. May 11 I estimated the number to be at least 500, and quite a number of them had already hatched. By July 7 all the eggs had hatched, so there were in the nest at that time only the workers and 500 or more larvæ, all being the offspring of worker eggs. No more eggs were laid and none of the larvæ pupated during the rest of the summer nor the following winter, although I kept them all the time in a warm room and gave them plenty of food. The first cocoons were spun on July 4, 1910, when 8 of them were formed. The exact length of the larval period could not be determined, but it must have been more than a year, since a considerable number of the eggs had hatched by July 7, 1909. July 18, 1910, there were 30 cocoons in the nest and a small bunch of worker eggs were laid. It had been over a year since any eggs had been laid in the nest. More eggs were laid later on—about 50 or 60 altogether; not nearly so many as the year before. However, a large number of the workers had died during the year and many of the larvæ had been eaten, so that the colony was not nearly so large as the year before. July 24 the first adult emerged; a second, July 25; a third, July 26; and a fourth, July 27. These were all males. This gives a pupal period of 20, 21, 22, and 23 days for these males. This nest was examined every day during the summer. Cocoons continued to be formed and adults

continued to appear until the last of September, and although I watched carefully for the appearance of callow workers, every adult proved to be a male. These males did not seem to do well, as there were never more than 15 or 20 males in the nest at the same time; but there were certainly more than 100 that emerged. This agrees with the general opinion that the offspring of unfertilized eggs of ants, as well as of bees, are always male, although Mrs. Comstock (Wheeler, '03) obtained normal workers from worker eggs. In a small queenless colony of *Formica schaufussi* that I watched, the offspring from worker eggs were all males. This brings up the interesting question as to whether the fertilized eggs of a fecundated queen ever produce males. Certainly they do not the first year, and most probably not the second. It is worthy of note that the same conditions which will develop winged females in a colony, that is, optimum conditions of food, temperature, and moisture, will also cause the workers to lay eggs and thus bring about the production of both the sexual forms.

The probable life of a colony is but a year or two years longer than that of the queen which founded it. After the queen dies the eggs laid in the nest will all be worker eggs and produce males. In strong colonies a few eggs would also be laid the second year, but the next year the colony would perish, or perhaps serve as a host for some species whose queen is temporarily parasitic upon *L. niger americanus*, as I have shown to be the case with *Lasius umbratus* var *minutus* (Tanquary, '11). Or it may serve as the host of young dealated, fertilized females of the same species, just descended from their nuptial flight, as I have shown that at times such queens may be adopted by small queenless colonies of this species ('11). The death of the queen the year before must account for my finding large colonies of this species which contained many hundreds of males but no females.

SUMMARY

1. Dates for which I have evidence of nuptial flights of *Lasius niger americanus* are September 5, 9, 18, 20, 19 to 29, October 4, 11, and 18.

2. The flights generally occur in the afternoon between 3 o'clock and 6 o'clock.

3. The time of a flight is partly determined by weather conditions.

4. Fertilization probably takes place in the nest.

5. The young queens eat a large proportion of their eggs.

6. The length of the different stages varies with conditions. The larval stage may extend over more than a year.

7. The average number of adults produced in a season was eleven, and the maximum number, twenty-seven.

8. The number of eggs laid by a queen depends upon the amount of nourishment she receives. In large colonies she may lay at the rate of more than one hundred eggs per day.

9. During the winter, nests of this species contain only dealated females, workers, and larvæ.

10. The winter quarters of this species are at about the same depth as those of the summer.

11. Ants taken from winter quarters in a frozen condition resume their normal activities at once upon being thawed out.

12. A single colony of *L. niger americanus* may carry through the winter more than one thousand eggs of *Aphis maidiradicis*.

13. A small percentage of the pupæ of this ant are naked, some of them owing to a failure of the larvæ to attach their first silken threads. Naked pupæ occur among those of a first-year colony as well as in older colonies.

14. The workers seem to be able to produce queen larvæ by furnishing plenty of food.

15. The workers will eat some of the larvæ, even though plenty of food is provided.

16. If a colony of workers is heavily fed it will produce a large number of eggs.

17. The adults from such eggs in all my colonies were males.

18. A colony probably does not continue to exist longer than the second year after the death of the queen. Such a colony may adopt a young fertilized female of the same species just descended from the nuptial flight, or may serve as host for the queen of another species that is temporarily parasitic upon *Lasius niger americanus*.

19. Colonies of *Lasius niger americanus* are founded in one of two ways; (1) by the typical method or (2) by the adoption of recently fertilized females by a small queenless colony.

ADDITIONAL NOTES

In one of my Fielde nests I noticed one day a larva with its anterior end lying against one of the eggs, which it seemed to be eating in the same way as described earlier for the small bits of egg yolk. On examining with a lens I could see that about one half of the egg

was already eaten and that the larva was still feeding. This may be one reason why the workers keep the eggs and the larvæ separate.

The sense of taste seems to be well developed in ants. They quickly discriminate between honey and sugar water and much prefer the latter to the former. On one occasion, instead of using sugar water, as usual, I placed a drop of honey in each nest. Generally the drop of food was discovered almost immediately and within a few minutes surrounded by the eager workers. On this occasion I examined the nests a few minutes after the introduction of the food, and in only seven out of the 26 colonies were there any ants at the honey, and only a few in those cases. On another occasion I introduced a drop of honey and sugar water at the same time in the light chamber of the Fielde nest containing a large colony. The honey was placed nearer the opening into the dark chamber where the ants stayed, while the sugar water was placed farther beyond it and near the refuse heap. The water was quickly surrounded, while only a few ants stopped at the honey, although they had to go around the honey to get to the sugar water. After a few minutes some of the ants began, as is their custom, to carry the dead ants, empty pupa-cases, etc., from the refuse heap and place in the liquid food, but in this case it was very striking to see the way in which the ants carried bits of debris around the sugar water in order to deposit them in the honey, while the feeding ants were passing around the honey to get to the sugar water. After a few minutes there were 13 dead ants placed in the honey and only 1 in the sugar water. This shows clearly that the purpose of such behavior on the part of the ants is to cover up objectionable substances and not to enable them the better to get at the food.

The queens do not often eat from the food chamber as the workers do, but I have seen them drinking sugar water a number of times. They will also cover the sugar water with bits of debris, and in some cases the queens stuck to the cover pane small pieces which they had torn from some black blotting-paper I had in the nest, as though to help shut out the light. They will also bury their larvæ when the latter are ready to spin their cocoons and will clean the cocoons after they are finished.

The ants often use bits of sponge and other debris to block up the passageway between the two chambers of a Fielde nest as though to shut out the light from the other chamber. In the same way I have had colonies of *Aphænogaster fulva* block up a passageway to shut out queens of *A. tennesseensis* which I was using for temporary parasitism experiments. Is this intelligence?

Although most of the winged forms of this species leave the nests in summer or early autumn, I have a note from Messrs. W. P. Flint and G. E. Sanders, reporting the finding of winged females in a nest at Galesburg, Ill., October 29, 1909.

II. Experiments on the Trail Formation and Orientation of the Common House Ant, *Monomorium pharaonis* L.

The little creatures that form the subject of these experiments forced themselves upon my attention by interfering seriously with my regular work and making themselves a general nuisance in the laboratory. They had a nest in some inaccessible place in the walls of the building, from which they formed regular trails to any substance in the laboratory, such as insect specimens, fruit, meat, sugar, etc., which they found suitable for food. A piece of fruit left lying on a desk in the laboratory was sure to be found by some wandering worker, and in an hour or so a regular trail would be formed leading to it, along which hundreds of the little workers would pass to and fro in the course of a few minutes.

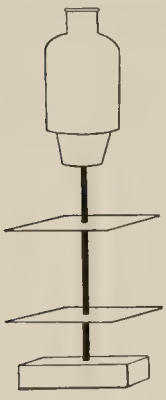
For my regular experiments I was keeping in Fielde nests a number of colonies of the common corn-field ant, *Lasius niger americanus*, which I often fed with sugar dissolved in water. The little *M. pharaonis* could crawl in under the roof-panes of these nests to the food provided for the *Lasius* colonies and many times caused the death of an entire colony in a single night. I do not know just how the *L. americanus* ants were killed. I never saw a *M. pharaonis* attack a living worker of the former species, but in some way its presence in the nests in such large numbers so irritated the corn-field ants as to cause their death. I have seen workers of *M. pharaonis* attack a queen of *L. americanus* that was already weakened to such an extent that she was unable to right herself when lying on her back.

The regularity of the trails, the closeness with which they were followed, and the extreme sensitiveness of the ants to slight breaks in their trail, made by rubbing the finger across it or placing some odoriferous substance or even a small piece of clean paper upon it, interested me, and induced me to perform some experiments to determine whether they depended entirely upon a chemical sense, located in the antennæ, to find their way, or whether they possessed also a sense of direction. While I was working on this problem other questions of a similar nature presented themselves which I tried to answer by experiments, some of which are given below.

After a number of preliminary experiments of one kind or another I used the following simple device to serve my purpose. I took an ordinary spindle-file with a base 2½ inches square, from the center of which extended upward, 7 inches in height, a cylindrical rod ⅛ inch in diameter. On the sharp point of this rod I stuck a circular piece of cork, 1 inch in diameter, which served as a support for a bottle containing sugar dissolved in water. Before placing the bottle of sugar-water on the cork I would cause the ants to form a trail to the bottle sitting on my desk; then I would replace the bottle with the file having the bottle on top, usually with 50 to 100 ants feeding from it. So many of these ants in wandering back from the bottle of sugar-water would meet the ants at the base of the file, that soon the trail would be continued up the rod to the bottle.

EXPERIMENT NO. 1

After a distinct trail was formed, I removed the cork with the bottle just long enough to thrust the rod through the center of two pieces of clean white note-paper, 2¾ inches square, one of which I placed one third, the other two thirds, the distance up the rod, so that the whole apparatus now had the appearance shown in the figure.



In order to get down, the ants now had to go out to the edge of the papers on the upper side and return to the rod on the under side. It was several hours before they formed a distinct trail, since they wandered about in confusion on the upper side of the papers and did not like to go over the sharp edges. When the trail was formed it led down the side of the bottle nearest the nest, down the rod on the same side, then in a straight line out to the middle of the edge of the paper towards the nest, back to the rod on the under side in the same line and over the lower paper in the same way, so that the trail on it was exactly beneath the one on the upper paper, then on down the rod and back to the nest.

After a good trail was formed I turned the top paper a few degrees to the right when no ants were on it. The next ants that reached the paper, both from above and from below, instead of following in the same direction followed the old trail, which extended at an angle of a few degrees from its former direction. I then turned the lower paper a few degrees to the left with the same result, that is, the ants followed the trail. I continued turning the top paper to

the right and the lower to the left until there was a difference of 180 degrees in the direction of the trails on the two papers. The ants still followed the trail. I continued turning the papers until both trails again led the same way but exactly opposite to their first direction, with the same result. Then I tried turning the papers through an angle of 90 degrees and even 180 degrees at one turn, but always with the same result. The first ants that reached the paper after turning it through so large an angle, were a little confused by the slight break in the trail, and sometimes a few of them would get lost and wander about for a while, until, striking the trail, they would start off in a straight line.

The above experiment I repeated a great many times and always with the same result; the ants followed the trail absolutely without regard to change of direction. This shows that, at least after the trail is formed, the ants, if they do possess a sense of direction, are not guided by it in finding their way back to the nest, but slavishly adhere to their trails, although the fact that the trails were formed on the side of the bottle and towards the edges of the paper nearest the nest indicates that in forming their trails a sense of direction may play some part. Later on I repeated the experiment, using circular cardboard disks, 4 inches in diameter, instead of square pieces of paper, and found that the trails were formed in the same way, although quite often there was a difference of a few degrees in the direction of the trails on the two disks, and in some places they even extended in opposite directions. Usually, however, they extended in nearly the same direction.

EXPERIMENT NO. 2

To determine whether the direction from which the light comes influences the ants in finding their way.

In some of the foregoing tests the apparatus was sitting near a window, so that when the disks were turned through an angle of 180 degrees the relation of the light to the trail was exactly reversed. This, however, made absolutely no difference in the behavior of the ants.

In order to make another test, one evening, at 7:30, I placed an incandescent light 2 feet from one side of the apparatus. At 8:45 p. m. I changed it to about the same distance from the opposite side. So far as I could judge from their behavior, the ants did not even notice the change. I repeated this experiment many times, and always with the same result.

EXPERIMENT NO. 3

Can ants of this species recognize a trail laid down by other individuals belonging to the same or to another colony?

It would seem in the highest degree improbable that each one of these hundreds of ants following the trail did so only after it had found the food independently or had followed other ants and laid down its own trail, but Miss Fielde in "Further Study of an Ant" (1901) makes the statement concerning another species, *Aphænogaster fulva picea,* that each ant lays down its individual trail, which can not be recognized by other ants of the same colony. In order to test this point with *M. pharaonis* I brought seven ants from another room of the building and placed them, one at a time, on one of the cardboard disks. In every instance the ant wandered about until it struck the trail, which it then followed, sometimes to the nest and sometimes to the food. To be sure, the ant did not in every instance, especially when excited, recognize the trail the first time it struck it, but almost without exception the trail was recognized sooner or later and followed. It is very improbable that these ants had been on the trail before; but to make the test more sure I isolated a number of them for several days, during which I caused trails to be formed on new disks. Placing these ants on the disks I found that they followed the trail just as the others had done. In each instance I was careful to place the ants to be tested on the disks at a time when there were no other ants there. These experiments were also to serve another purpose and will be referred to again.

To find out whether ants from one colony could recognize a trail laid down by ants of a different colony, I had a friend whose pantry was infested by this same species, and whose house was at least a quarter of a mile from the insectary, bring me a number of them in a bottle. I found that they recognized the trail just the same and started to follow it, but that they were invariably attacked and killed when they met the other ants.

EXPERIMENT NO. 4

To determine the length of time a trail can be recognized after it has ceased to be used.

January 25.—3:05 P.M. I remove the top disk, B, having previously marked the position of the trail by placing a small ink spot on either side of it.

4:15 P.M. I replace disk B in such a way that the trail leads out in the opposite direction from what it did before, and in the opposite

direction to that on the lower disk. With almost no confusion the ants, both coming and going, led out over the old trail. The disk has been removed 1 hour and 10 minutes.

January 26.—8:17 A.M. I remove disk B again.

11:17 A.M. I replace disk B so that the direction of the trail extends at an angle of 90 degrees from the one on the lower disk. Without hesitation the ants start out from the stem over the old trail, but the first three from each direction go only two thirds of the way to the circumference and then turn back. The fourth ant from above goes over the edge, hesitating a little, and meets the ant on the under side. After that the ants go on as before. The disk has been removed 3 hours.

11:20 A.M. I remove the lower disk, A.

5:30 P.M. I so replace disk A that the trail on it extends in the opposite direction from that on the other disk. The first ants that reach the disk appear lost and wander about, but still seem to recognize the trail faintly when they cross it. In about a minute, one ant on the upper side of the disk follows the trail to the edge and goes to the under side, where it follows the trail on to the nest. Not all the ants seem to be able to recognize the trail, and many wander about over both surfaces of the disk, sometimes following it for a short distance and then leaving it.

5:55 P.M. Eleven ants wandering on the upper surface and nine on the lower surface. Every once in a while an ant goes from one surface to the other on the trail.

5:58 P.M. Sixteen ants wandering on the upper surface.

January 27.—8:00 A.M. The trail which the ants are using this morning does not coincide exactly with the old trail. It goes over the edge of the disk at the same point, but at an intermediate point between the circumference and the stem it is about ½ inch to the side of the old trail. The disk has been removed 6 hours and 10 minutes.

January 26.—6:00 P.M. I remove disk B.

January 27.—8:05 A.M. I replace disk B. The ants can still follow the trail, but it is evidently very indistinct to them. The first ants from either direction start out over the trail, very slowly however. They move a little way, stop, go on, turn around and go back to the stem and then wander about over the disk, apparently searching for a more distinct trail. Nearly all those that go over the edge of the disk, however, do so at the point where the old trail goes over. The ants follow the trail quite closely on the under side, although they move very slowly. I think the ants feel less like wandering

about on the lower surface because of their inverted position, and they therefore "smell" their way much more carefully.

8:45 A.M. The ants are still wandering about on the upper surface of the disk. A number of them cross and recross the trail many times without seeming to notice it. On the lower side they are following the trail closely.

9:30 A.M. The ants are not yet following the trail on the upper side.

10:10 A.M. The ants still wandering on the upper side, but occasionally one follows the trail. Trail closely followed on the lower side.

11:05 A.M. More ants are following the trail, but they still wander about considerably on the upper surface.

11:55 A.M. The ants are now following the trail on both surfaces.

February 2.—4:00 P.M. The last few days I have been using new disks, C and D. I remove the top disk, D, and replace it with a fresh one, E.

February 3.—8:00 A.M. I remove disk C and replace disk D. D has been removed 16 hours. The ants can still distinguish the trail and some of them follow it, sometimes turning and retracing their steps, sometimes wandering out to the side and then back, a few of them, however, following it with very little or no hesitation.

9:30 A.M. The ants are following the trail as though nothing had happened.

3:00 P.M. I remove disk E.

February 4.—8:00 A.M. I replace disk C. It has been removed 24 hours. The ants begin to follow the trail with about the same readiness that they did the one yesterday that was removed for 16 hours. There seems to be even less confusion, but this is probably due to the fact that not nearly so many ants are passing this morning.

2:30 P.M. I remove disk D.

5:30 P.M. I replace disk E. It has been removed 26½ hours. I can not make out positively whether any of the ants recognize the trail or not. I had placed a piece of fresh meat on the bottle in the afternoon, and a much larger number of ants are passing than usual. A great many ants are scattered over the surface of the disk. Some of them seem to follow the trail for a little way and then lose it, but I can not be sure that they do not just happen to follow the trail for a short distance. More of the ants pass from one surface of the disk to the other at or very near where the trail goes over the edge than at any other place. I watch them until 6:00 p. m. but can not tell whether they are going to follow the trail or not.

8:00 P.M. The ants are not using the old trail. They are still wandering a great deal, but seem to be following a trail at an angle of about 15 degrees to the right of the old one and 75 degrees to the left of the trail on the lower disk.

8:45 P.M. The new trail is now fairly definite.

February 9.—2:00 P.M. I remove disk E.

February 10.—3:15 P.M. I remove disk C and replace disk E. Disk E has been removed 25 hours and 15 minutes. Most of the ants do not recognize the trail, but a few of them seem to do so.

3:30 P.M. A great many ants are scattered over the disk. Now and then an ant seems to recognize the trail and follows it for a short distance, five or six of them following it over both surfaces.

4:00 P.M. Ants still wandering about on the disk, but occasionally one seems to follow the trail.

4:40 P.M. The ants are now following the trail with very little wandering.

February 11.—5:30 P.M. I replace disk C. It has been removed 26 hours and 15 minutes. I can not see that the first ants that reach the disk recognize the trail. I watch them for 10 minutes; most of them do not follow the trail but wander about on both surfaces. A few of them, on the lower surface, seem to recognize the trail and several pass over the edge at or near the place where the trail passes over.

February 12.—10:00 A.M. The ants are following the old trail.

February 16.—1:45 P.M. I remove disk C.

February 17.—5:00 P.M. I replace disk C. It has been removed 27 hours and 15 minutes. The first ants that reach the disk do not seem to recognize any trail. Some start back to the nest or the food, and some wander about on the disk.

5:10 P.M. I notice two ants follow the trail on the lower surface, go over the edge, and then wander about on the upper surface. A great many ants are wandering about on the upper surface of each disk.

5:20 P.M. Now and then an ant follows the trail on the lower surface and loses it on the upper surface.

February 18.—8:00 A.M. The ants have formed a new trail, about 65 degrees to the left of the old one and about 15 degrees to the right of the one on the lower disk.

The above experiments show that a trail formed over cardboard by *M. pharaonis* may be recognized after it has ceased to be used for 26 hours and 15 minutes. No doubt factors such as the material over

which the trail is formed, atmospheric conditions, etc., would cause a difference in the length of time a trail could remain unused by the ants and still be recognized.

An idea of the number of ants passing over the trail in these experiments may be gained from the following counts taken at various times.

January 22.—Between 11:45 and 11:50, sixty-one ants passed a certain point on the trail, twenty-five going to the food and thirty-six to the nest.

January 25.—Between 3:00 and 3:05, ninety-seven ants passed a certain point, sixty-two going to the food and thirty-five to the nest.

January 26.—Between 9:45 and 9:50, seventy-eight ants passed a certain point, thirty-nine going each way.

February 2.—Between 11:32 and 11:37, seventy-four ants passed a certain point, thirty-six going to the food and thirty-eight to the nest.

EXPERIMENT NO. 5

Can ants recognize which direction on the trail leads to the nest?

Of the seven ants (Experiment 3) placed on the trail from another room of the building, three followed it to the food and the other four to the nest. There is here the possibility that three ants sought the food purposely and that four purposely followed the trail to the nest.

January 28.—2:45 P.M. With a camel's hair brush I pick up from the edge of the jar upon which the apparatus is resting today, an ant, No. 1, going to the food, and place it on top of the lower disk near the trail. It crosses the trail without seeming to recognize it, goes around the disk once, crosses the trail again, goes half-way around the disk again, and then reaches the stem, where it takes the trail and goes to the food, which it reaches at 2:50.

2:55 P.M. I take No. 2 from the top disk, going towards the nest, and place it on the lower disk near the trail. It recognizes the trail and after a little hesitation starts towards the food. When it reaches the stem it turns and follows the trail back to the nest.

3:07 P. M. I take No. 3 from the edge of the jar, going to the food, and place it on the lower disk near the trail. It crosses the trail, wanders about for a short time, then strikes the trail and starts to follow it to the nest. It goes over the edge of the disk to the stem, then on past the stem and seems to be lost for a short time, then back to the stem and down it to the edge of the base. There it

turns and retraces its steps over the base as far as the stem, then turns again and continues toward the nest.

3:32 P.M. I take No. 4 just as it reaches the top disk, coming from the food, and place it on the lower disk near the trail. It starts on the trail toward the nest, crosses to the under side of the disk, then turns and comes again to the upper side, wanders about for a while near the edge, goes to the lower side, back to the upper, then on the trail again to the lower side, follows the trail to the edge of the base, turns and goes back about half an inch, then turns again and continues towards the nest.

3:50 P.M. I take No. 5 from the edge of the jar, going to the food, and place it on the lower disk near the trail. It crosses the trail three times. The fourth time it comes to the trail it follows it to the food, which it reaches at 3:55.

4.07 P.M. I take No. 6 just as it reaches the top disk, coming from the food, and place on top of the lower disk near the trail. It follows the trail at once to the nest.

It will be noticed that the three ants taken as they were coming from the food, Nos. 2, 4, and 6, finally followed the trail to the nest, and that of the three taken as they were coming from the nest, one, No. 3, goes back to the nest, while the other two, Nos. 1 and 5, continue to follow the trail to the food. This is, of course, insufficient data to base any conclusions whatever upon, so, later on, I isolated two groups of ants on islands in a pan of water for several days, providing one group with plenty of food and keeping the other without food. I then transferred them, one at a time, to the new trail which I had caused to be formed in the meantime. The results, however, were not very satisfactory, so I shall not give them in detail. It was impossible for an ant to follow the trail very far without meeting others, and there was often a tendency for the ant placed upon the trail to turn about and follow others which it met, although sometimes it merely stroked antennæ with them and went ahead.

An experiment along this same line consisted in removing one of the disks and replacing it with the lower side uppermost, thus reversing the direction of the trails on both surfaces. This caused some confusion, but I think no more than was caused by merely removing the disk and replacing it in the same position. Although the above experiments are not at all conclusive, yet it seemed to me that the ants merely recognized the trail as such, and could not tell which direction on the trail led to the nest. I did not find in the behavior of these ants any support for Bethe's "Polarized Trail" theory. (Bethe, 1902.)

Whenever I caused a new trail to be formed, or placed on a new disk, I always watched carefully for any signs of communication when the first ants from the food met those from the nest. One would think that these conditions would be ideal for any power of communication on the part of the ants to manifest itself, since the ants on one side knew the way back to the nest and were searching for the food, while those on the other side knew the way to the food and were trying to get back to the nest. Yet I failed to observe anything in the behavior of the ants which I could interpret as communication. To be sure the ants meeting under the above circumstances always stopped and stroked antennæ, but when they separated each continued to wander as aimlessly as before, and the gap in the trail was finally bridged by the ants from one side accidentally striking the trail on the other. I do not, of course, mean to say that communication among ants does not exist. In fact, stridulation, gestures, postures, etc., on the part of the ants undoubtedly do represent some form of communication, as has been shown by Wheeler, Forel, and Wasmann. I do mean to say that with this particular species and under these particular conditions I failed to observe anything, which, from its effect upon the behavior of the ants, I could interpret as communication.

As a rule the queens of *M. pharaonis* do not leave the nest to feed, but quite often when I placed out some food particularly attractive to the ants, such as a piece of fresh beef, especially if the room was quite warm, a number of queens would follow the trail out to it. Ordinarily, however, they did not feed, and I think they were only induced to come out by the fact that a very large number of workers was passing in and out. During the winter I captured fifteen dealated queens from this one colony.

The queens follow a trail just as the workers do, and without having been over it before. One rather amusing illustration of this was exhibited when I placed a queen, previously isolated, upon a disk having a newly formed trail on it. I first removed the disk from the apparatus and held it in my hands during the experiment. The queen wandered about until she struck the trail, which she at once began to follow. She followed it over the edge to the lower surface, where she continued until she reached the hole in the center of the disk through which the rod had passed. After a little hesitation she crawled through the hole to the upper surface, coming out on the trail above, and thus making it continuous. She continued following

the trail, going over the edge to the lower surface, back through the hole in the center, until she had completed the round more than a dozen times. After that she seemed to realize that she was not getting anywhere and began to wander about.

CONCLUSIONS

1. A trail once formed by *Monomorium pharaonis* is followed regardless of any change made in its direction.

2. Change in the direction from which the light comes does not influence this species in following its trail.

3. Ants of this species can recognize a trail laid down by other individuals of the same or of a different colony.

4. *Monomorium pharaonis* can still recognize a trail sufficiently well to follow it, after it has ceased to be used for at least 26 hours and 15 minutes.

5. The behavior of ants of this species when placed upon the trail seems to indicate that they do not recognize which direction leads to the nest.

I do not, of course, attempt to apply these conclusions to all ants, for a study of the literature upon ants, or, better still, a study of the various species of ants themselves, will soon convince one that there is probably as much diversity in the habits of different species of ants as there is in the habits of different species of mammals or of birds. It is probable, however, that they may apply more or less closely to those species of ants which have very small eyes and travel in regular files.

III. Studies on the Embryology of *Camponotus herculeanus* var. *ferrugineus* Fabr. and *Myrmica scabrinodis* var. *sabuleti* Meinert

METHODS

The eggs for the studies on the first species were obtained from two large colonies of *Camponotus herculeanus* var. *ferrugineus* which I kept through the winter in large Fielde nests (Fielde, 1904). The temperature of the laboratory in which they were kept was about 70 F., and remained practically constant day and night. Each colony contained one queen. The ants were fed on dead insects, insect larvæ, sugar water, pieces of lean meat, and the yolk of egg. The queens began laying in December and January, and laid during the rest of the winter. Sometimes I allowed the eggs to accumulate in the nest until the first ones began to hatch and then killed the entire bunch, thus getting all stages. The egg periods varied, but averaged between twenty-five and thirty days. Very often by the time the first eggs began to hatch there were from one hundred to two hundred eggs in the nest. Sometimes I removed the queen and a few workers to another nest and removed the eggs each day, placing them with other workers, in order to estimate the time. I found it a very difficult matter to get the later egg-stages in this way because of the fact that the workers ate many of the eggs; but it was necessary to have the eggs with workers or with a queen in order to prevent their being attacked by fungi. In order to remove the eggs or the queen, the entire colony was first stupefied with cold.

The eggs were killed and fixed in a saturated solution of mercuric chloride in 35% alcohol to which had been added 2% of glacial acetic acid. The solution was used at a temperature just below the boiling point. The eggs were then transferred to 70% alcohol, in which they were left until the following day, or later. While in 70% alcohol the embryos were dissected out from the membranes surrounding them by means of fine dissecting needles. This could be accomplished, after a week or two of practice, with little difficulty. The embryos were then stained in toto in Grenacher's alcoholic borax-carmine, Delafield's or Ehrlich's hæmatoxylin, or orange G, and then, after decolorizing, carried up through the various grades of alcohol

to some clearing agent. I always over-stained the material and then decolorized in acid alcohol. For the study of the entire embryo a rather faint stain is much the better; but for embryos that are to be sectioned, a heavier stain is desirable.

For clearing I used xylol, cedar oil, and clove oil. The two latter I found cleared a little better than xylol, and were more desirable also because of the fact that they do not evaporate so rapidly. I kept the embryos in the clearing agent in a watch crystal; but for drawing and for the study of any particular embryo, I removed it to a microscope slide upon which I had built up a ring of cerasine to such a height that the depth of the cell formed was just a little greater than the thickness of the embryo. Then by moving the cover-glass the embryo could be made to assume any desired position. An embryo can be kept in such a cell for weeks at a time. For the study of certain structures I found it very desirable to cut the embryo in two and to remove all the enclosed yolk. The spiracular openings, for instance, I could not make out until I had resorted to this method.

For sectioning the earlier stages I did not remove the egg membranes. I found that by piercing the chorion and allowing the egg to remain in melted paraffine for from eight to twelve hours it sectioned very well. These eggs were all stained in toto in Ehrlich's hæmatoxylin and then counterstained on the slide with orange G, by the use of a saturated solution in 95% alcohol. I found that by using this method I did not over-stain with the hæmatoxylin; that I got a much better stain than by staining on the slide; avoided the necessity of running the slides through the different grades of alcohol, and hence much danger of losing sections by washing them off; and saved a great deal of time. The orange G differentiated the yolk from the superficial layer of protoplasm or from the germ layers. The sections were cut with a Minot's rotary microtome and mounted with Meyer's albumen fixative. The drawings were made in outline with an Abbé camera lucida.

THE EGG

The egg of *C. ferrugineus* may be described as somewhat Paramœcium-shaped, with a blunt, narrow anterior end, and with its greatest transverse diameter about one third the distance forward from the posterior end. The length of the egg is about 1.4 mm. and the transverse diameter is about .5 mm. When the egg is laid the posterior end makes its appearance first.

There are two external membranes, the chorion and the vitelline membrane. The chorion is made up of two membranes: an outer, or exochorion, and an inner, or endochorion. It is difficult to distinguish these two layers in sections, but sometimes when the eggs are removed from the fixing agent to 70% alcohol the inner layer separates from the outer one in bubble-like areas, and the two can then be further separated by needles. The vitelline membrane is somewhat thinner and much more delicate than the chorion. The former stains more heavily with hæmatoxylin, while the latter stains more heavily with orange G. I was not able to distinguish any structure that I could identify positively as a micropyle. Ganin (1869) states that there is a single micropyle at the posterior end of the egg. Blochmann (1884) states that a micropyle occurs at the animal pole or upper end of the egg. It is probable that he means by "animal pole" the posterior end of the egg, since he says that he found what he took to be the egg nucleus and the sperm nucleus at that end of the almost ripe ovarian egg. In the freshly laid egg the nuclei always occur at the posterior end.

If a freshly laid egg be sectioned longitudinally, it will be found to present the appearance shown in Plate I, Fig. 1. On the outside is the chorion, which stains rather deeply with orange G; and inside the chorion, closely investing the protoplasm, is the vitelline membrane, which takes the hæmatoxylin stain. On the inside of the vitelline membrane is a comparatively thick layer of peripheral protoplasm, much thicker at the posterior than at the anterior end or at the sides. The part of this layer in the posterior one-third of the egg is noticeably different from that of the anterior two-thirds, that at the anterior end being much more vacuolated, with a tendency toward network formation, while that at the posterior end is almost devoid of vacuoles. Numerous small yolk granules are seen embedded in this protoplasmic layer, especially at the posterior end. In many places the small granules are found fitting into small pocket-like depressions. In other places the outer edges of these depressions, meeting, enclose the granules in vacuoles. This indicates the manner in which the yolk granules probably become embedded in the peripheral layer of protoplasm.

Another respect in which the protoplasmic layer at the posterior end differs from that at the anterior end and at the sides is in the presence of an immense number of minute rod-like bodies which almost completely fill the protoplasm at that end of the egg and stain readily with hæmatoxylin. Blochmann ('84, pp. 245-246) mentions finding these bodies in the ovarian eggs of *Camponotus ligniperdis*

and *Formica fusca,* but says that they disappear with the formation of the yolk in the egg. He found them later ('87 and '92) in certain other insects, and similar bodies have since been found by Forbes (1892) in the cæcal glands of various *Heteroptera,* and identified by him as bacteria, and by Wheeler ('89, p. 306) in the egg of *Blatta germanica.* Recently they have been proved to be bacteria by Mercier ('07), who grew them in cultures. Those I found in *C. herculeanus* stain deeply with eosin and with methylene blue but do not take the Gram stain. So far as I know this is the first time these bacteria have been seen in ants' eggs in this country.

The peripheral layer of protoplasm at its inner edges passes out into what appears in sections as a delicate network of protoplasm which extends through the entire egg. This delicate network shows very clearly because of the fact that the protoplasm stains more strongly with hæmatoxylin while the yolk granules stain more strongly with orange G. Both protoplasm and yolk will take either stain, but the yolk stains much more readily with orange G, while the protoplasm stains much more readily with hæmatoxylin, thus producing a very good differentiation. Near the posterior end of the egg, and to a less extent near the anterior end, this network leaves many large vacuoles between which occur yolk granules. Near the center of the egg the yolk granules are massed to such an extent that there are very few or no vacuoles. These yolk granules vary in size, and also somewhat in shape, but approach a globular form, and are very finely granular. They range in size from a diameter of about .005 mm. to a diameter of about .027 mm., with an average diameter of about .018 mm.

In the peripheral layer of protoplasm at the posterior end of a freshly laid egg, or of one at a somewhat later stage (one to thirteen hours), is found a very large, much vacuolated, heavily staining nucleus (Figures 1 and 2). In addition to this, there is found situated very near the large one, in some of the eggs, a much smaller nucleus (Figures 1 and 3), having the same appearance as the large one except that it is generally denser, that is, less vacuolated. In one of my slides the two nuclei were just touching each other. In sections of several somewhat later stages, still more nuclei of exactly the same appearance were found. These nuclei all had the same appearance structurally. I did not see in those I examined any appearance of karyokinetic figures. Of two eggs killed just after being laid, one contained but the one large nucleus, the other contained the large nucleus and a small one. Of three eggs one hour old, one had only the one large nucleus, one had the large one and one small

one, and the other had the one large nucleus and two small ones. One egg four hours old showed but the one large nucleus. Of five eggs from one to four hours old, one had two nuclei, the large one and one small one; each of the other four had only the large nucleus. One egg, from one to twelve hours old, had but the one large nucleus.

In an egg killed eight hours after laying, I found three nuclei, each about one third as large as the large ones mentioned above, and two smaller ones, all having the same characteristic vacuolated appearance. All five were in the peripheral layer of protoplasm near the posterior end of the egg. In another egg eight hours old there was but the one large nucleus at the posterior end of the egg; but in addition to this, in the midst of the yolk at about one-third the distance from the anterior end, appeared a few small irregular stellate nucleated masses of protoplasm, having exactly the same appearance as the ones that appear successively more numerous in somewhat later stages. In an egg eleven hours old, there was but the one large nucleus at the posterior end, and near the anterior end there were a few small irregular nucleated masses of protoplasm. In addition to these, scattered throughout the yolk in the posterior half of the egg, were a number of small stellate masses of protoplasm, most of which had exactly the same appearance as those at the anterior end except for the fact that I could not see that they were nucleated. Some of them looked very much as though they were detached fragments of the large nucleus, having the same vacuolated appearance. The yolk is now changing its appearance, becoming liquefied, the yolk granules breaking down and the vacuoles increasing in size and number. In a thirteen-hour stage I found only the one large nucleus. In an egg twenty hours old I found one nucleus, very large and very irregular (Figure 4), at the posterior end in the usual position of the large nucleus. In addition to this, in the yolk occur a number of small, rather deeply staining, vacuolated masses that have the same appearance structurally as the large nucleus. They appear either to be made up entirely of cytoplasm or entirely of karyoplasm, that is, there is no part more deeply staining than the rest to indicate that they are nucleated masses of protoplasm. The large nucleus was .09 mm. across, and the largest of the small masses was .025 mm. in diameter. In the anterior half there are scattered throughout the yolk near the center of the egg, a number (about twenty altogether) of stellate masses of protoplasm with small, globular, deeply-staining nuclei. These generally occur in pairs, indicating their origin by division. The conditions which are described above must be similar to those found by Weismann in *Cynipidæ*. "According to Weismann,

in *Rhodites* and *Biorhiza aptera* (*Cynipidæ*) the first cleavage-nucleus divides at first into nuclei which shift apart in the direction of the longitudinal axis of the egg, and, according to their position, are known as the anterior and posterior "pole nuclei." While the anterior nucleus remains inactive for some time, the posterior, by a kind of budding (?), gives rise to numerous nuclei, which take part in the formation of the blastoderm. The anterior nucleus, on the contrary, after the completion of the blastoderm, is said to produce by division the nuclei of the so-called inner germ-cells or yolk-cells."* In the case of *Camponotus*, however, the anterior cells go to make up at least the greater part of the blastoderm.

In the next stage I have, (marked one day old,) the nucleated masses of protoplasm are beginning to arrange themselves in a regular layer in the yolk just a little distance in from the peripheral protoplasm (Figure 5). This layer is more regular and the nuclei are more numerous in the anterior than in the posterior half of the egg; furthermore, the nuclei lie nearer the periphery. There are still a great many nuclei scattered indiscriminately through the central portion of the yolk. Division seems to be going on much more rapidly in the anterior half, and many karyokinetic figures can be seen, sometimes six or eight in the same section.

In a stage a few hours later the nuclei at the anterior end have migrated outward until they form a loose layer in the peripheral protoplasm. Towards the posterior end the nuclei do not divide so rapidly and do not reach the peripheral protoplasm as soon as at the anterior end, so that a longitudinal section of this stage has the appearance shown in Plate II, Figure 6. Figure 7 shows a section through the peripheral layer of protoplasm at the anterior end parallel with the surface.

FORMATION OF THE BLASTODERM

By the time the nuclei have reached the periphery at the posterior end of the egg the layer of protoplasm in the anterior half has become divided by deep fissures, running in from the outside, into columnar cells, each cell containing one nucleus. The nucleus has in each case migrated outward to the extreme distal end of the cell. These cells are not formed, however, over the entire surface. They form a cap over the anterior end, and extend on the ventral surface, backward, about half-way to the posterior end. The dorsal half of

*Quoted from Korschelt aud Heider ('99, p. 264).

the egg is still uncovered with cells. The nuclei here lie embedded in the peripheral protoplasm, which has become much thinner. There are still many nucleated stellate cells scattered throughout the yolk. This stage, which represents conditions at the beginning of the second day, is illustrated by Plate II, Figure 8.

During the second day (Pl. III, Fig. 9) cells are formed over the entire surface of the posterior half of the egg in the same way that they were formed over the ventral surface of the anterior half the first day. These cells differ from those at the anterior end in being much larger and broader. The protoplasm is mostly at the distal end of the cell, while the basal part contains an immense number of yolk granules. At this stage those cells at the posterior end contain also a very large number of the bacteria mentioned above. The nuclei in these cells lie in the distal ends, as do those of the anterior end, but they are not nearly so easily made out. On the ventral surface the cells of the posterior half meet those of the anterior half about half-way between the two poles to form a continuous layer. The transition from one type of cell to that of the other is not a gradual one but is rather abrupt. On the dorsal surface the layer of cells from the posterior end has grown forward about the same distance as on the ventral side, but the layer of cells from the anterior end has not grown backward to meet it, so there is still a small area on the dorsal surface just back of the anterior end that is as yet not covered with cells. The protoplasmic layer has changed here until there is nothing but a thin membrane separating the yolk from the vitelline membrane (Fig. 10).

The cells that were described above as being formed the first day on the ventral surface of the anterior half have changed decidedly in appearance. They have become longer and more columnar and taper somewhat at the base. This layer of cells forms the beginning of the germ band. At their proximal ends they merge into the protoplasm which has formed a layer lying between the yolk and the cells. In the posterior half this layer almost disappears in the protoplasmic network; but in the anterior half it is much heavier and really forms a syncitium, since it contains quite a number of nuclei. This syncitium seems to act as a kind of "feeder" to the layer of cells, since it is the seat of rapid nucleus formation, nuclei appearing here in various stages of mitosis, and since the nuclei being formed here appear to migrate outward, drawing with them a part of the syncitial protoplasm, thus forming new cells. These migrating nuclei can be found at the distal ends of the cells just forming in this way, anywhere between the protoplasmic layer and the

level of the distal ends of the mature cells. This view of the function of the syncitial layer is further supported by the fact that in two places in this layer there are longitudinal thickenings containing many more nuclei extending from the anterior end backward as far as the end of the germ band, and these thickenings occur near the lateral edge of the germ band, or where there is greater need for rapid cell-formation. Furthermore, a larger number of the cells of the germ layers are connected at their bases with the syncitial thickening than with any other equal area of the layer. This is shown by Figure 10, which represents a cross-section through the posterior part of the germ band at this stage, that is, just a little in front of the middle of the blastoderm. It will be noticed that there are large blastoderm cells on the dorsal side, showing that here this layer has grown farther forward on the dorsal side than the point on the ventral side where the blastoderm cells meet the posterior end of the germ band, which in this stage is about the middle of the egg. Figure 11 represents a transverse section of the same egg taken farther forward, through the region where there is still a small area on the dorsal side that is not as yet covered by the blastoderm cells; the dorsal side of the section is limited, consequently, by the thin protoplasmic layer mentioned above.

In Figures 9, 10, and 11, most of the cells, both of the germ band and of the blastoderm outside the germ band, are seen to contain a very large number of yolk granules which have passed through the protoplasmic layer into the bases of the cells. The large cells of the blastoderm especially are distended with the yolk granules, the amount of yolk in many cases being greater than the amount of protoplasm. At this stage many of the yolk granules have broken down, leaving a granular liquid mass. The stellate yolk cells have almost disappeared, only a few being found scattered throughout the yolk mass. At the posterior end of the section shown in Figure 9 may be seen a group of cells lying just inside the blastoderm which are smaller than the cells of the blastoderm. Also, in view of their later development, mention should here be made of certain cells in the posterior ventral part of the blastoderm which have become very greatly enlarged, and at their bases contain a large number of yolk granules. The protoplasm in these cells is denser than in those just at the end. One such cell is shown in Figure 9.

An examination of the section shown in Figure 11, shows that the cells in the middle of the germ band at this point have taken on a different appearance from those at the sides. Instead of the narrow columnar cells with their nuclei out at their extreme distal ends

which appear at the sides, and also in the middle a few sections back of this point, there are more or less globular cells having their nuclei near their centers. They are undergoing rapid division, as is shown by the fact that a large number are seen in various stages of mitosis. These cells, including about the middle one-third of the germ band, are seen to be sunk below the level of the columnar cells on either side, forming a broad shallow depression. This depression, which has been termed by some embryologists the *middle plate*, represents an invagination from which will arise the mesoderm. At this stage the middle plate occurs only near the anterior end.

In a stage a day later (three days old) the small area on the dorsal side that still remained uncovered by the blastoderm has become overgrown by the layer of cells, so that we now have the blastoderm and the germ band completely enclosing the yolk (Fig. 12). Sections through the egg at this stage show us that the cells of the blastoderm are not all alike. In the first place we have in the anterior half of the ventral surface, the germ band, the surface cells of which are columnar and stain deeply with hæmatoxylin (Fig. 12). Just posterior to the germ band comes a layer of large polygonal cells containing only a small amount of protoplasm in comparison with the large amount of yolk material within them. The protoplasm, which is rather dense, but does not stain so deeply as in the cells of the germ layer, is all together, while the yolk granules fill the rest of the cell. This layer extends almost to the posterior end, but just before that end is reached a few enormously enlarged cells occur which closely resemble those just described, but are conspicuous because of their great size. They appear to be multinucleate, although their nuclei do not show up very well, and to enter into close relationship with the posterior end of the inner protoplasmic layer. They contain a number of vacuoles, and, like the cells just described, they contain a very large amount of yolk material, and their rather dense protoplasm stains more lightly than that in the cells of the germ band. At the posterior end, and extending forward from these almost half the distance on the dorsal side, occurs a layer of rather large polygonal cells which contain only a few yolk granules. The protoplasm of these cells is less dense than that of the cells just described, but it takes a deeper stain, and hence these cells are very easily distinguished from the others. About half-way between the anterior and posterior ends, these cells give way to cells of the same kind as those which occur just posterior to the germ band on the ventral surfaces. These cells extend forward on the dorsal surface to meet the germ band at the anterior end of the blastoderm.

At the anterior end of the germ band, a transverse depression, or invagination, occurs, beneath the floor of which there has developed a large cell-mass composed of more or less circular cells having deeply staining nuclei. These cells represent a further development of the cells mentioned as occurring in the two-day stage below the middle plate. The middle plate at this stage, with its accompanying cells beneath, extends back a little farther than in the two-day stage.

Just a little distance in front of the transverse depression, or invagination, the large cells which cover the anterior half of the dorsal part and extend to the anterior end of the blastoderm give way to a one-celled layer of somewhat flattened loosely-connected cells, which resemble the cells of the germ band in their structure and in the manner in which they stain. This layer, which at this stage extends backward only a very little way, not yet bridging the invagination, represents the beginning of the serosa. At the posterior end of the germ band also, there is a slight transverse groove, from the posterior border of which a few cells extend forward over the posterior end of the germ band. These cells, however, are not different in character from those just posterior to them, that is, they have not changed their shape so as to form a layer of flattened cells similar to the one extending backward from the anterior end. At both the anterior and posterior ends the lateral edges of the germ band are sinking slightly below the level of the other cells so that both grooves are slightly crescentic, the horns of the anterior one extending backward, and these of the posterior one extending forward.

The inner protoplasmic layer, which lies between the cells and the yolk mass, is very greatly thickened at the anterior end, where the greatest cell growth is taking place. The posterior end of this layer seems to have contracted somewhat, ending bluntly, and leaving a space between it and the posterior end of the blastoderm. Near the dorsal side the group of small cells, mentioned in the description of the two-day stage as lying just inside the posterior cells of the blastoderm, are seen to be applied to this blunt, posterior end of the inner protoplasmic layer, although they still retain a loose connection with the surface cells. The bacteria mentioned above can still be seen in the posterior cells. There are still a very few cells scattered throughout the yolk mass.

In the sections I have representing the four-day stage there are few further changes of importance. The serosa has grown farther backward over the germ band, extending about half its length. Its anterior attachment has begun to retreat somewhat over the antero-

dorsal part of the blastoderm toward the posterior end, so that the anterior end of the blastoderm is now completely enclosed by the serosa. This retreating of the attachment of the amnion apparently takes place by a kind of progressive delamination from the blastoderm cells successively farther back. The anterior end of the germ band has retreated somewhat and the anterior cell-mass has increased in size. The middle groove and the middle plate have grown farther backward but have not reached the posterior end of the germ band, while at the anterior end the surface is again even, the middle groove having grown over. The transverse depression at the posterior end of the germ band has become somewhat deeper, but the blastoderm cells at the posterior edge of this depression have grown forward but little if any farther than in the last stage described.

In a stage five days old (Pl. IV, Fig. 15), the serosa has grown backward on all sides almost to the posterior end of the blastoderm, enclosing the large cells of the blastoderm and the germ band. At the posterior end of the germ band the serosa did not unite with the forward-projecting cells from the posterior end of the transverse groove, but continued to grow on backward, enclosing those cells with the posterior end of the germ band.

At the position of the transverse groove mentioned in preceding stages, the germ band dips downward and backward diagonally and then continues to grow toward the posterior end, following the thin layer of peripheral protoplasm. At this stage the backward growth from the lower end of the incline has proceeded only for the length of a few cells. From that point backward toward the posterior end of the blastoderm the layer of inner protoplasm, which although very thin is easily distinguishable, rises again toward the surface, leaving a very broad depression, in which lie a mass of large blastoderm cells covered by the serosa.

At the anterior end the germ band turns upward and then backward again on the dorsal side, and since the dorsal and ventral parts are now connected by a layer of cells, this gives to the anterior end of the germ band the appearance of a closed tube with the lumen opening backwards. The layer of thin epithelial cells forming the dorsal surface of this tube extends backward at this stage, as a delicate layer, to about the level of the transverse groove near the posterior end of the germ band on the ventral side. From this point the wall of the tube, which widens somewhat here, extends backward as the inner protoplasmic layer to the posterior end of the blastoderm, where, with the same layer from the sides and the ventral surface, it forms the other closed end of the tube. Between the antero-dorsal

surface of this tube and the serosa lies a mass of cells in an irregular layer, of the same nature as those lying in the hollow on the ventral surface. The axis of the rounded, tube-like, anterior portion of the germ band does not coincide with the longitudinal axis of the entire egg, but is anteriorly inclined towards the ventral surface. The hollows on the dorsal and ventral surfaces give to the germ band and the inner protoplasmic layer a somewhat slipper-shaped appearance in longitudinal vertical sections, the heel being formed by the germ band and the toe by the inner layer of peripheral protoplasm, the longitudinal axis of the slipper lying diagonal to the longitudinal axis of the egg. Encircling the toe of the slipper and extending forward on the dorsal surface about half the length of the blastoderm are the rather deeply-staining cells mentioned as occurring in this position in the three-day stage, but the layer has pushed forward farther on the dorsal side at this stage. Most of these cells contain the bacteria mentioned above. At the anterior end of this layer on the ventral surface occur the large vacuolated multinucleate cells described above. The group of cells originating at the anterior end of the ventral groove has increased greatly in size so that the anterior end of the germ band now appears as a solid mass of cells. The ventral groove and the cells of the middle plate have just about reached the posterior end of the germ band.

At the age of six days the germ band has grown backward on the ventral side along the inner layer of peripheral protoplasm to the most posterior place occupied by that layer in the region of the middle of the egg near the posterior end (Fig. 16). It has grown back as a layer several cells in thickness in the median line, thinning out to a delicate one-celled layer laterally. Over the anterior half this layer is continuous with the delicate one-celled layer extending backward from the antero-dorsal part of the germ band, forming here a dorsal closure of the embryo. This dorsal closure has not yet been effected over the posterior part. The layer of inner peripheral protoplasm now contains a great many more nuclei, so that it forms a loose nucleated layer extending over the entire dorsal area and lying just inside the delicate one-celled layer which is continuous with the edges of the germ band.

At the very posterior end of the germ band a significant change is beginning at this stage. The germ band now extends back to the point where the peculiar, large, multinucleate cells and the large heavily-staining cells, mentioned as occurring at the posterior and the postero-dorsal part of the blastoderm, begin. At this point the germ band forms a knot-like thickening, and from this thickening

there extend several finger-like processes composed of the small germ-band type of cells. These finger-like processes work themselves in between the large blastoderm cells, tending to enclose them in meshes. The significance of this process will be seen in later stages.

The embryo, as it may now be called, has shortened somewhat in length and at the same time has increased in circumference, so that the large blastoderm cells mentioned in the five-day stage as occurring in hollows on the dorsal and ventral sides of the germ band have been crowded out of these positions, those on the dorsal side being forced into the anterior end of the egg, and those on the ventral side now occupying the postero-ventral part of the egg. These cells contain a great deal of yolk and are evidently absorbed as food, since they gradually disappear in later stages. The ventral side of the embryo now lies next to the vitelline membrane, and the dorsal side is separated from the vitelline membrane by only the single layer of the large heavily-staining blastoderm cells, which now extend well towards the anterior end of the embryo, and which at the posterior end are beginning to be enclosed by the finger-like processes from the posterior end of the embryo.

In an eight-days stage (Fig. 17) the small cells which originally grew out as finger-like processes from the posterior end of the germ band have increased in number to such an extent that they now enclose all the large heavily-staining blastoderm cells mentioned above and the large multinucleate cells in a perfect meshwork, extending as far forward dorsally and laterally as the large cells extend, that is, almost to the anterior end of the embryo. At the posterior end these large cells are in a group which becomes thinner as it extends forward, until near the anterior end it becomes a layer one-celled in thickness. This group ends posteriorly with the large multinucleate cells. The cells forming the network are very small, but are easily detected by the presence of the deeply-staining nuclei. At the posterior end of the embryo where the germ band broke up into the finger-like processes consisting of the small cells, the outermost of these processes, which is now a very thin, delicate membrane, extends backward over the large multinucleate cells, and enclosing the group of large heavily-staining cells continues forward to meet the thin layer extending backward on the dorsal side of the embryo, thus forming the dorsal closure, and thus including, as a part of the embryo, the large cells which originated in an entirely different part of the blastoderm from that which formed the original germ band (Pl. III, Fig. 9). The inner layer of peripheral protoplasm lies just beneath this network, thus enclosing it between two membranes. This inner layer

has, scattered through it, very large and heavily-staining nuclei. One of these nuclei is shown in the figure situated at the anterior end and another at the posterior end, in very noticeable thickenings of the layer. The nuclei of the serosa have increased greatly in size and are now very conspicuous, lying just beneath the vitelline membrane.

The serosa is the only embryonic membrane that develops in the case of *Camponotus* to enclose the embryo entirely. This develops, as has been seen, by a backward growth as a single layer from the anterior border of the cephalic groove. At the posterior end of the germ band it does not unite with the posterior edge of the caudal groove, but grows on backward to enclose the rest of the blastoderm. This differs from the typical method of formation of embryonic membranes in two ways: (1) the entire membrane is formed by a growth from the cephalic fold, the caudal fold being rudimentary; (2) the growth occurs as a single and not as a double layer. There is, therefore, no amnion formed over the ventral surface of the embryo. The dorsal closure, however, has been effected, as has been described, by a delicate one-celled layer which is continuous with the edges of the germ band. This layer is similar in structure to the serosa. It grows out from the edges of the germ band, spreads dorsally, and closes over to form the dorsal body-wall of the embryo; hence it is to be regarded as the amnion.

Graber has shown ('88, pp. 144-146) that there are two embryonic membranes in *Polistes gallica, Formica rufa,* and *Hylotoma berberidis.* He says that the inner layer becomes closely applied to the germ band and is indistinguishable from the latter. In *Camponotus* I have been unable to find more than the one layer on the ventral side of the embryo. Carrière ('97, pp. 396) found but the one layer in *Polistes gallica* and *Chalicodoma muraria,* and Bütschli (1870) found but one in *Apis.* Ganin, who studied the development of several species of *Formica* and *Myrmica,* also says that there is but one embryonic layer.

The ventral part of the embryo, which is in the position of the original germ band, is now much narrower than the original germband and is in the form of a narrow ridge-like thickening along the median ventral line, widening out at the anterior, and, to a less extent, at the posterior end. Figure 18, Plate V, represents a cross-section of this stage showing the ridge-like thickening on the ventral side, and the large cells forming a layer extending about half-way around on the ventral side. The anterior widening shows the fundaments of appendages and of the stomodæal invagination, but the proctodæal invagination does not appear until several days later.

In an embryo ten days old the ventral thickening widens somewhat and the large dorsal cells have pushed farther around towards the ventral side. This process continues in succeeding stages, and in a cross-section of an embryo at the age of fourteen days we have the appearance shown in Figure 19. Here the ventral thickening has become wider and somewhat thinner and is composed of two layers: an outer, compact ectodermal layer; and an inner, somewhat looser layer of mesodermal cells. The large cells from the dorsal side have grown around a little farther toward the ventral side. These cells, together with the small cells which form a network among them, form a layer which is beginning to separate slightly from the thin ectoderm dorsally and laterally, leaving a small space occupied by scattered cells. The invagination of the proctodæum has not yet developed at this stage.

In a somewhat later stage, represented by Figure 20, (the exact age of these later stages can not be given,) the ventral thickening has widened somewhat, and in the middle of this thickening there are two longitudinal elevations, inside of which we see the beginnings of the nerve cord. These appear in cross-section as two circular areas of cells overgrown with the ectoderm. The layer of mesoderm cells which we found lying just below the ectodermal thickening in the fourteen-day stage has here split into two parts, one part lying on each side of the developing nerve cord.

The layer of large cells which has been growing around from the dorsal side has now reached the median ventral line, and the two edges unite to form a circular layer. The ultimate fate of these cells is now evident. They, together with the network of small cells which grew out from the posterior end of the germ band, and with the scattered cells of the inner layer of peripheral protoplasm, have formed the mesenteron. These cells which were enclosed in the network and were originally very large, are now much smaller, and there is no longer a clear distinction between the various kinds of cells which went to make up the layer. The mesenteron has now completely separated from the surface ectoderm, leaving a well-developed body cavity.

The mesenteron ends blindly at both ends. Its shape may be seen from Figures 22 and 24. Its wall is thick, appearing in sections as a protoplasmic network enclosing the cells. This network is especially noticeable on the inner border.

By this time, appendages have been formed and the invaginations of the stomodæum and proctodæum are well developed. The development of the appendages and the further development of the

alimentary canal and of the nervous system will be given on the following pages.

THE DEVELOPMENT OF THE EXTERNAL FORM

Figure 21, Plate V, represents an embryo about twelve to fourteen days old. The embryo occupies a position somewhat nearer the posterior than the anterior end of the egg, with a mass of large, faintly-staining cells at each end. The serosa encloses these cells with the embryo. The ventral thickening appears as a ridge along the median ventral line, curving around at each end in the form of a large letter C. At the anterior end there is a slight widening of this ridge which indicates the beginnings of the procephalic lobes. At the posterior end the thickening passes insensibly into the darker posterior dorsal portion of the embryo. This is due to the fact, as we have noticed in the sections, that the posterior end of the original germ-band breaks up into finger-like masses of small cells which form a network around the large heavily-staining cells of the posterior end of the blastoderm. A very slight indication of segmentation has already made its appearance, due to the beginning of the formation of the ganglia of the ventral nerve-chain, the thickenings of which may be seen in lightly stained embryos. Sections of this stage show that the invagination of the stomodæum has just begun, but there is no indication of it as one looks at the entire embryo. The invagination of the proctodæum has not yet begun.

Figures 22 and 25 represent a stage in which the layer of cells from the inner posterior dorsal part of the embryo has grown around to the ventral side along its entire length, thus completing the mesenteron, which now has the appearance of a pear-shaped sac, closed at both ends, the small end being the anterior one. This pear-shaped sac enclosing the yolk almost fills the embryo, though a small space is noticeable between it and the outer layer or ectoderm, this space representing the body cavity. At the anterior end of the embryo there is a well-developed, thick-walled, backward-projecting, U-shaped invagination of the outer ectoderm which represents the stomodæum. The posterior end of the stomodæum almost reaches the anterior end of the mesenteron. The invagination of the proctodæum is also well-developed at this stage. At the anterior end of the embryo at this stage the appendages are already well formed. Just in front of the stomodæum is a median evagination of the ectoderm projecting anteriorly and dorsally, which when viewed from the side appears as a pear-shaped body, but when viewed from a postero-

dorsal direction appears as a narrow oblong with its greatest length extending transversely to the long axis of the embryo. This is the fundament of the labrum. On each side of the labrum is a wide lobe-like thickening of the ectoderm, the two constituting the procephalic lobes, and on each side of these is a small knob-like thickening, representing the antennæ. The antennæ are not so well-developed as in *Myrmica* (see Pl. VIII, Fig. 33). The fundaments of the antennæ were noted by Ganin ('69), but he did not know what they represented. He says: "Es muss hier noch bemerkt werden dass man in solchen Entwicklungs-stadium auf den Seitentheilen jedes Kopflappens ein besonders rundliches Hockerchen beobachten kann; übrigens existiren diese Hockerchen nur kurze Zeit und haben keine definitive Bedeutung; in den späteren Entwicklungsstadien kann man sie nicht mehr unterscheiden." Wheeler (1910, p. 72) mentions the presence of traces of the antennæ in the embryo of *Formica gnava.*

Back of the stomodæum occur three pairs of lobe-like evaginations, the fundaments of the mandibles, maxillæ, and labium respectively. On the three following segments occur three similar lobe-like thickenings which are somewhat smaller than those representing the mouth parts. These represent the three pairs of thoracic legs. Back of the thoracic segments occur ten other segments, upon which occur very small paired tubercles representing abdominal appendages. On each side of the second thoracic segment occurs an irregular slit-like opening, the first thoracic spiracle. A pair of such openings occurs on the last thoracic segment and one on each of the following ten abdominal segments. Figure 23, Plate VI, represents a slightly older stage than Figure 22, Plate V. The dorsal part of the embryo has been removed, the yolk taken away, and the ventral part of the embryo straightened out to show all the segments. This corresponds to the stage of *Formica gnava* figured by Wheeler (1910, pp. 69). At this stage the ventral thickening extends almost halfway around to the dorsal side.

Figure 24 represents a later stage, in which the embryo has straightened, the mouth parts extending directly forward instead of ventral as in Figure 22. The mesenteron is smaller, and shows as a regular oval in the middle of the body. Its ends are in contact with the now more fully developed stomodæum and proctodæum, although communication between the two has not yet been established. The stomodæum extends backward as a narrow tube, while the proctodæum is a much shorter, somewhat oval sac.

The posterior border of the head is indicated by a constriction, but there is no differentiation between thorax and abdomen at this

stage. The mouth parts are grouped nearer together and tend to bend in over the opening of the stomodæum. The two lobes representing the labium have grown together at their bases, making one plate. The small knobs representing the antennæ are still present, but are very inconspicuous. The papillæ representing the thoracic legs and the abdominal appendages have now disappeared.

The ganglia can be distinguished easily in faintly stained specimens at this stage. There is a double chain of ten abdominal ganglia, the last three of which are united in a compound ganglion in which the three constituent ganglia are easily distinguishable by their faintly-staining central portions. The double chain is continued in the thorax as three separate pairs of ganglia, the anterior one of which connects with the subœsophageal ganglion, which is easily seen to be made up of three united pairs of ganglia. The subœsophageal ganglion is connected with the supraœsophageal ganglion by a pair of commissures as usual.

Figure 25 represents an embryo at just about the time of hatching. It has practically the form of the young larva. The mesenteron has the same form as in the preceding stage except that its anterior end has narrowed considerably, giving it somewhat the appearance of the neck of a bottle. This neck is open at the anterior end, and encloses the posterior end of the stomodæum which is now open also, thus forming the valve-like connection between the stomodæum and the mesenteron. The proctodæum has changed considerably in shape. It has a middle portion which is wide and bladder-like, from the posterior end of which a narrow tube-like part leads back to the anus, and from the anterior end of which a short narrow part passes forward to end blindly against the posterior end of the mesenteron, the connection between these two divisions of the alimentary canal not yet having been formed.

The mouth parts are practically the same as in the larva, and the antennæ have disappeared. The nerve cord presents practically the same appearance as in the preceding stage except that the last three abdominal ganglia and the three parts of the subœsophageal ganglion are more closely united.

THE DEVELOPMENT OF THE EXTERNAL FORM OF THE EMBRYO OF *Myrmica scabrinodis* Nyl.

Since a colony of *Myrmica scabrinodis* var. *sabuleti* which I had in the laboratory was yielding an abundance of eggs while I was waiting for my *Camponotus* queen to begin laying, I decided to

make a study of the development of the external form of the embryo of that species.

The eggs were killed and fixed in the same manner as has been described for the eggs of *Camponotus*. The eggs of *Myrmica* are much smaller than those of *Camponotus*, their greatest diameter being about .45 mm. and their shortest diameter being about .35 mm. They may be described as broadly ovate in form, with one end slightly smaller than the other. As in the eggs of *Camponotus*, there are two external membranes, the chorion and the vitelline membrane, the chorion being composed of two layers—ectochorion and endochorion.

The appearance of the first differentiation of the germ band from the undifferentiated blastoderm may be described as follows. At the anterior pole occur two somewhat oval-shaped thickenings of the blastoderm lying side by side with a clear area between them. These thickenings are slightly raised above the surrounding blastoderm. The edges facing each other are nearly straight, sometimes concave, while the outer edges are convex. At the opposite pole is a more or less circular denser area surrounded by a clear ring. This clear ring is connected by a light streak with the clear space between the two thickenings at the anterior pole. On each side of this light streak, a slight thickening of the blastoderm indicates the beginning of the germ band. The two oval thickenings at the anterior pole are the procephalic lobes.

Figure 26, Plate VI, represents an early stage in which the embryo is curved around the yolk mass in the form of a capital C. There are slight indications of segmentation. The anterior end is thicker and wider than the posterior end, indicating the earlier development of the head region. The anterior and posterior ends are seen to be connected by the undifferentiated blastoderm.

Figure 27, Plate VII, represents a later stage, in which the body segments are clearly indicated. The anterior and posterior ends, both of which are thickened, the anterior much more than the posterior, more closely approach each other, and the layer connecting the two ends has a large knob-like thickening near its middle. This thickening is composed of a large irregular mass of cells, and seems to be caused by a crowding and pushing outward of the cells of the layer connecting the two ends, as these ends approach each other. This layer continues at the sides, covering the yolk, and connects ventrally with the edges of the germ band. From a direct dorsal view this thickening is seen to be made up of two parts, separated laterally. This would naturally be the case if the thickening were caused in the way that has been suggested, that is, by the coming

together of the anterior and posterior ends of the embryo and by the dorsal growth of the sides of the germ band.

The germ band has widened considerably, and now covers most of the ventral surface of the yolk. Figure 28 represents a view of the anterior end of the germ band at this stage, showing the procephalic lobes in front, the beginning of the evaginations representing the mandibles, maxillæ, and labium. At this stage there are only the faintest traces of the three pairs of thoracic appendages, and the invagination of the proctodæum has not yet begun.

In the stage represented by Figure 29, the curvature of the embryo is still greater, the anterior and posterior ends more closely approximating each other. The dorsal thickening between the anterior and posterior ends is present as before, and as a rule is somewhat larger than in the preceding stage. The segments are much more clearly differentiated, there being ten abdominal segments. The procephalic lobes have increased in size, and the lateral edges of the germ band have grown farther dorsally. The labrum is shown in Figure 30, which represents a dorso-frontal view of the same stage. Figure 30 shows also the extent of the invagination of the stomodæum and the lobe-like appendages representing the three pairs of mouth parts and the first two pairs of legs. Figure 31, which represents a slightly different view of the same stage, shows also the last two pairs of thoracic appendages and the first pair of abdominal appendages, and on these segments also appear the first three pairs of spiracles. The invagination of the proctodæum is shown at the posterior end.

Figure 32, Plate VIII, represents a later stage, in which the labrum is well developed, pushing out in front of the invagination of the stomodæum, which has pushed farther inward. In fact, the posterior border of the labrum is continued inward to form the anterior wall of the invagination. The procephalic lobes are larger and the germ band has grown farther over the yolk. The proctodæum now appears as a distinct U-shaped thick-walled invagination. The dorsal thickening, made up of a cluster of cells, has disappeared in this stage. In stages just a little earlier than this, a constriction develops at the base of this thickening. This fact, together with the fact that in such stages the thickening is very easily broken away from its attachment as the embryo is moved about in the clearing agent, leads me to believe that it takes no part in the development of the embryo. The membrane covering the yolk, from which this cluster of cells is formed, is homologous with what we have called the amnion in *Camponotus*. This cluster of cells, then, seems to correspond with the so-called amniotic dorsal organ which Wheeler

has described as occurring in *Doryphora* (Wheeler '89, pp. 356-358), but sections of the embryo at this stage do not show anything that would lead me to believe that it is absorbed into the yolk. The absence of such a structure in *Camponotus* illustrates one striking difference between the development in that genus and in *Myrmica*. In *Camponotus* the amnion becomes the dorsal body-wall.

At this age the segments are more deeply constricted off from each other. The three pairs of mouth parts are further developed, and the thoracic and abdominal appendages are present, although in a side view it is difficult to distinguish them from the body segments.

In the stage represented by Figure 33, the embryo is seen to be straightening somewhat, the posterior and anterior ends being farther apart. The segments are still more deeply constricted off from each other, and the lateral edges of the germ band have grown dorsad until they have almost completed the dorsal closure. The invagination of the stomodæum has grown farther inward, the posterior end of the stomodæum almost reaching the yolk. On the sides of the procephalic lobes appear the small tubercle-like thickenings which represent the antennæ. The labrum and the three pairs of mouth parts more closely approximate each other and tend to bend in over the opening of the stomodæum. This is shown better in Figure 34, which represents a frontal view of the same stage.

In the stage represented by Figure 35, the embryo has straightened still more, and the dorsal closure has been completed. The mouth parts still more closely approximate each other and bend in over the stomodæum. The thoracic and abdominal appendages have disappeared, as have also the antennæ. The stomodæum and proctodæum extend inward as far as the yolk, which is now enclosed in the somewhat pear-shaped mesenteron. The ventral segments are constricted off into blocks, three pairs in the thorax and seven in the abdomen, the last three abdominal segments having united together. In each of these segments a primitive ganglion is evident, and in the last abdominal segment three ganglia appear, showing the compound nature of the segment. In the head region three separate ganglia can be distinguished, for the subœsophageal ganglion appears in the whole embryo to be all in one part.

Figure 36 represents a stage just before the egg hatches, when the embryo has practically the form of the young larva. The embryo has now bent completely over so that the flexure, instead of being on the dorsal side as before, is on the ventral side. The thoracic region has lengthened considerably. The mouth parts are in their normal position for the larva and have practically the same form.

The stomodæum is discernible as a long narrow tube leading back to the mesenteron and connecting with it at about the level of the third thoracic segment. The connection is of the same valve-like character as has been described for the similar stage in the embryo of *Camponotus*. The proctodæum also is similar to that described for the corresponding stage of *Camponotus*. There is a wide middle part connected at one end by a short, narrow, tube-like part with the anus and similarly, at the other end, with the posterior end of the mesenteron. The connection between the proctodæum and the mesenteron has not yet been established. The segmentation is essentially as in the preceding stage; the last three abdominal ganglia and the three ganglia composing the subœsophageal ganglion are more closely united, however, and the supraœsophageal ganglion is larger than in the preceding stage.

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EXPLANATION OF PLATES

Abbreviations

a., amnion
1a., 1st abdominal appendage.
1a.s., 1st abdominal segment.
a.d.o., amniotic dorsal organ.
an, anus.
ant., antenna.
b., blastoderm cells.
b.c., body cavity.
ca.g., caudal groove.
c.c., cleavage cells.
c.g., cephalic groove.
ch., chorion.
c.n., cells forming network around large blastoderm cells.
co.g., compound ganglion.
d.p., dense particles of protoplasm or nucleoplasm, possibly derived from cleavage nucleus.
ec., ectoderm.
e.g.b., lateral edge of germ band.
f.c., large cells external to the embryo and surrounded by the serosa. Absorbed as food.
g., fundament of ganglion.
g.b., germ band.
i.p., inner peripheral protoplasm.
k.c., group of small cells applied to the posterior end of the inner peripheral protoplasm.
l., labrum.
la., labium.
l.b., large blastoderm cells.
l.c., large polynucleate cells of the blastoderm.
l.g., lateral groove.
m., mandible.
me., mesoderm.
mes., mesenteron.
mo., mouth.
mx., maxilla.
m.p., middle plate.
n., cleavage nucleus.
nu., nuclei of the cells.
p., proctodæum.
p.l., procephalic lobes.
p.n., protoplasmic network.
p.p., peripheral protoplasm.
r.n., remains of large nucleus.
s., serosa.
s.c., scattered cells of the body cavity.
sp., spiracle.
st., stomodæum.
su., supraœsophageal ganglion.
sub., subœsophageal ganglion.
t., thickenings of the inner layer of peripheral protoplasm.
1t., 1st thoracic appendage.
1t.s., 1st thoracic segment.
v., vacuole.
v.m., vitelline membrane.
y., yolk mass.
y.c., so-called yolk cells.
y.g., yolk granules.

Plate LVII

Fig. 1. Longitudinal section through the egg of *Camponotus* 1 hour old. × 52.
Fig. 2. Large nucleus found in posterior end of egg of *Camponotus* 1 hour old. × 360.
Fig. 3. Small nucleus found in posterior end of egg of *Camponotus* 1 hour old. × 405.
Fig. 4. Longitudinal section through egg of *Camponotus* 20 hours old, chorion removed. × 52.
Fig. 5. Longitudinal section through egg of *Camponotus* 1 day old. × 52.

Plate LVIII

Fig. 6. Longitudinal section through egg of *Camponotus* a little older than the stage represented by Fig. 5. × 52.
Fig. 7. Portion of a section taken through the layer of peripheral protoplasm of anterior end of egg of *Camponotus*. Same age as that represented by Fig. 6. × 405.
Fig. 8. Longitudinal section through egg of *Camponotus* 30 hours old. × 52.

Plate LIX

Fig. 9. Longitudinal section through egg of *Camponotus* 2 days old. × 52.
Fig. 10. Transverse section through blastoderm near posterior end of germ band. Same age as the one represented by Fig. 9. × 78.
Fig. 11. Transverse section through same stage as that represented by Figs. 9 and 10. Taken near anterior end of germ band. × 78.
Fig. 12. Longitudinal section through blastoderm of *Camponotus* at a somewhat later stage than that represented by Fig. 9. × 52.

Plate LX

Fig. 13. Transverse section through anterior end of blastoderm of *Camponotus*. Same age as that represented by Fig. 12. × 78.
Fig. 14. Transverse section through middle of blastoderm. Same age as that represented by Fig. 12. × 78.
Fig. 15. Longitudinal section through blastoderm of *Camponotus* 5 days old. × 52.
Fig. 16. Longitudinal section through blastoderm of *Camponotus* 6 days old. × 78.
Fig. 17. Longitudinal section through blastoderm of *Camponotus* 8 days old. × 52.

Plate LXI

Fig. 18. Transverse section through blastoderm of *Camponotus* 8 days old. × 105.
Fig. 19. Transverse section through embryo of *Camponotus* 14 days old. × 105.
Fig. 20. Transverse section through embryo of *Camponotus* 15-20 days old. × 105.
Fig. 21. Embryo of *Camponotus* 8-12 days old. × 52.
Fig. 22. Embryo of *Camponotus* showing development of appendages. × 52.

Plate LXII

Fig. 23. Ventral view of germ band of the same age as that represented by Fig. 22. The yolk mass has been removed and the embryo, which is normally curved over the yolk, has been straightened out. × 52.
Fig. 24. Embryo of *Camponotus*. A later stage than that represented by Fig. 23. × 52.
Fig. 25. Embryo of *Camponotus* at a stage just before hatching. × 31.
Fig. 26. Embryo of *Myrmica*. Early stage. × 91.

Plate LXIII

Fig. 27. Embryo of *Myrmica*, at a stage somewhat later than that represented by Fig. 26. × 114.
Fig. 28. Ventral view of anterior end of germ band of same age as that represented by Fig. 27. × 91.
Fig. 29. Side view of later stage of embryo of *Myrmica* than that shown in Fig. 27. × 91.
Fig. 30. Ventral view of same stage as the embryo shown in Fig. 29. × 91.
Fig. 31. A slightly different view of the same embryo. × 91.

Plate LXIV

Fig. 32. A later stage of the embryo of *Myrmica*. × 91.
Fig. 33. A still later stage of the embryo of *Myrmica*. × 91.
Fig. 34. Ventro-frontal view of same embryo as in Fig. 33. × 91.
Fig. 35. Embryo of *Myrmica* at a stage when it is straightening. × 80.
Fig. 36. Embryo of *Myrmica* just before hatching. × 91.

PLATE LVII

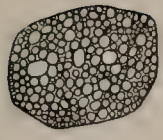


FIG. 2

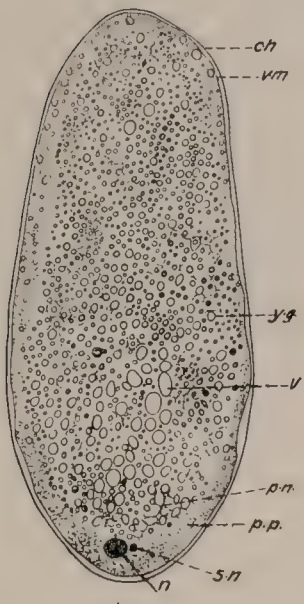


FIG. 1

FIG. 3

FIG. 4

FIG. 5

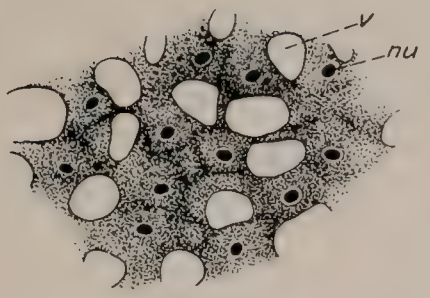


FIG. 7

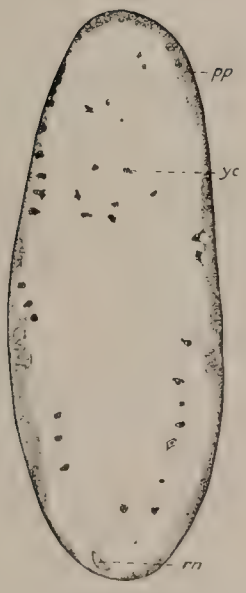


FIG. 6

FIG. 8

PLATE LIX

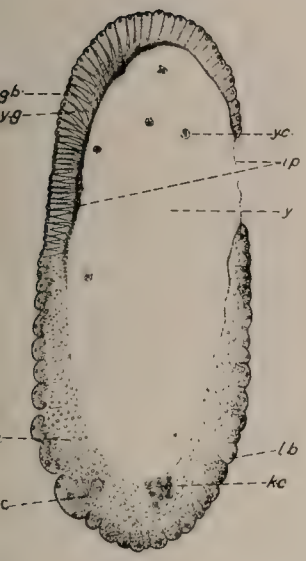


FIG. 9

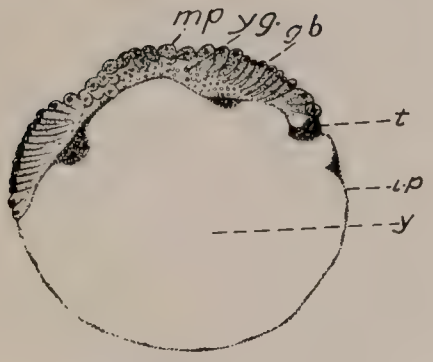


FIG. 11

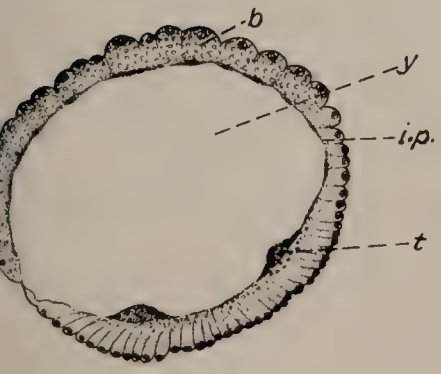


FIG. 10

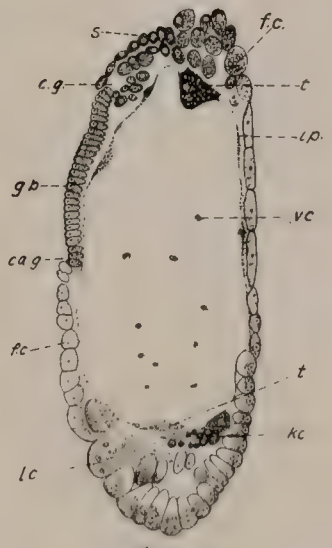


FIG. 12

PLATE LX

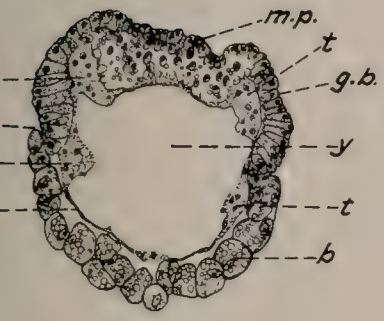
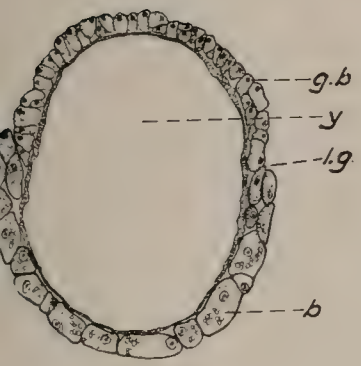


FIG. 13



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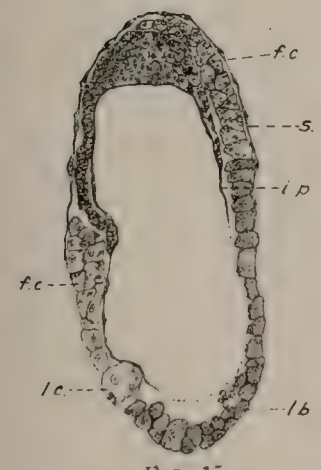


FIG. 15

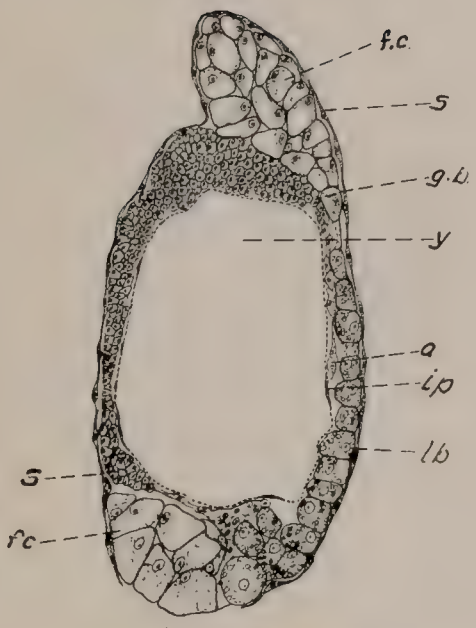


FIG. 16

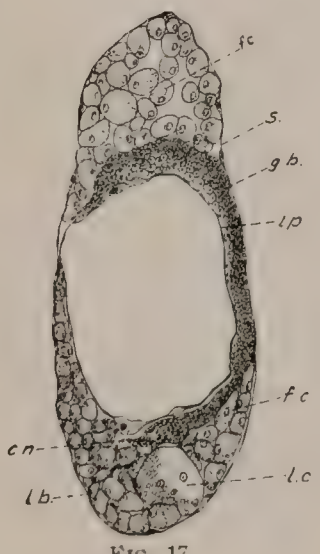


FIG. 17

PLATE LXI

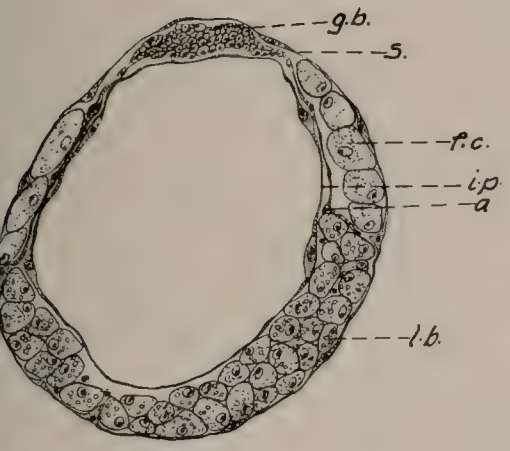


FIG. 18

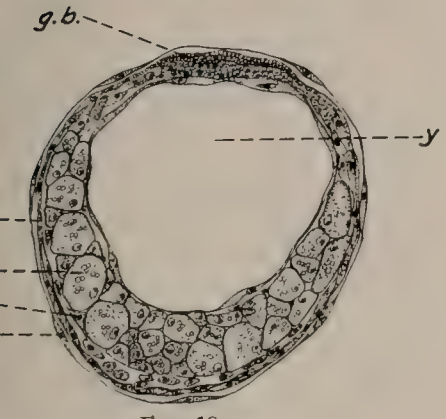


FIG. 19

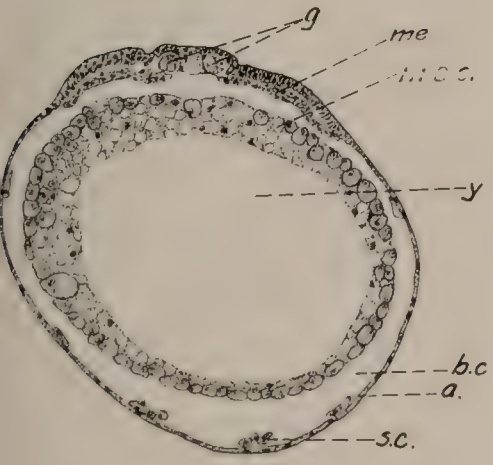


FIG. 20

FIG. 21

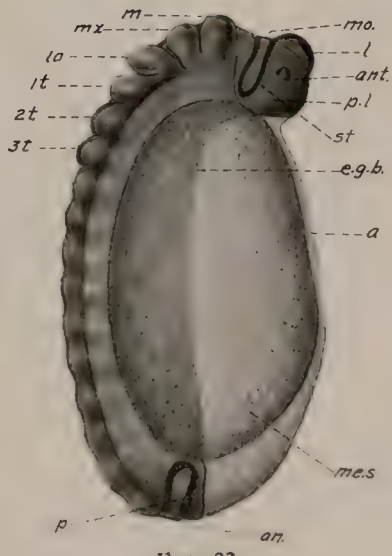


FIG. 22

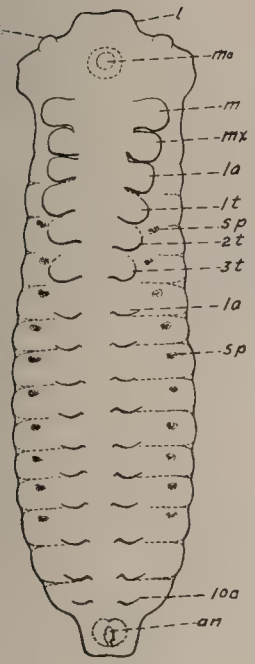


FIG. 23

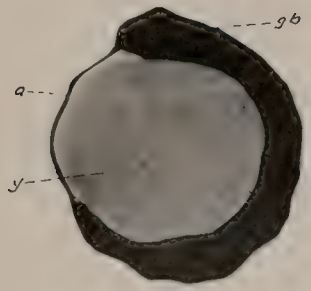


FIG. 26

FIG. 24

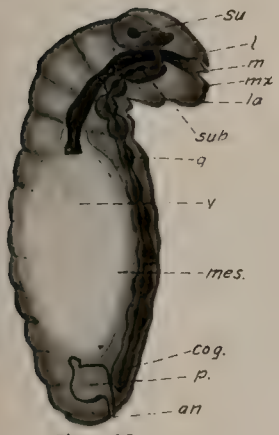


FIG. 25

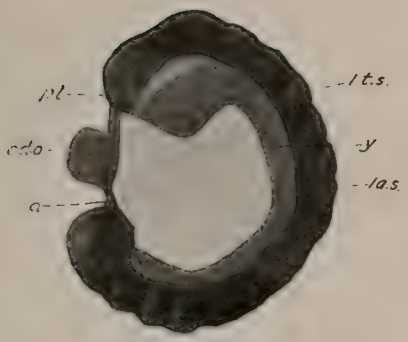


FIG. 27

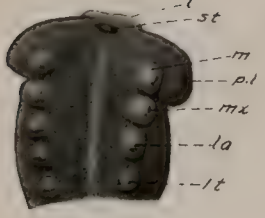


FIG. 30

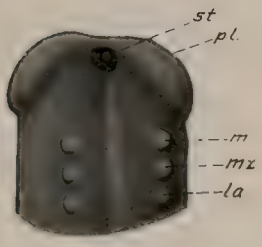


FIG. 28

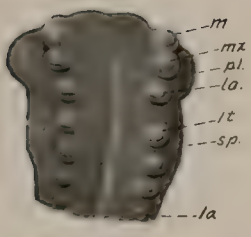


FIG. 31

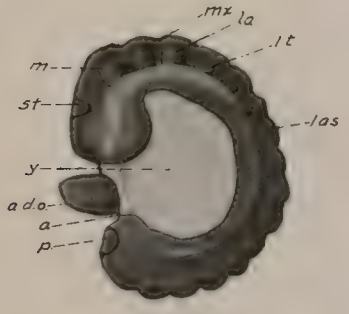


FIG. 29

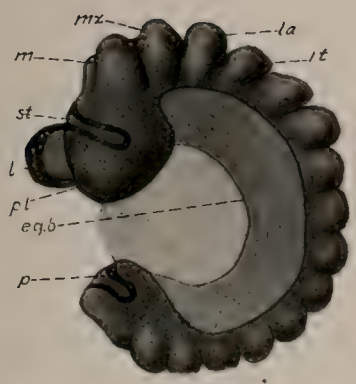


FIG. 32

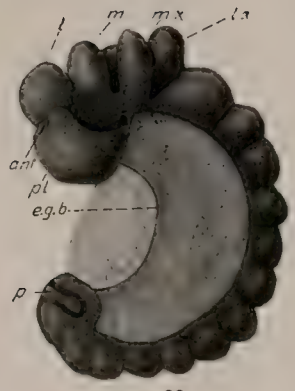


FIG. 33

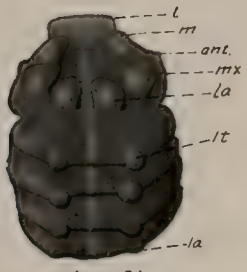


FIG. 34

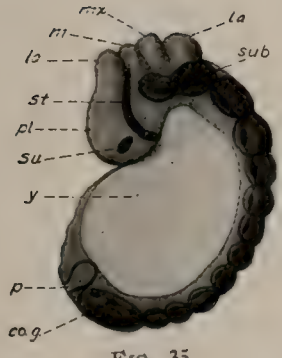


FIG. 35

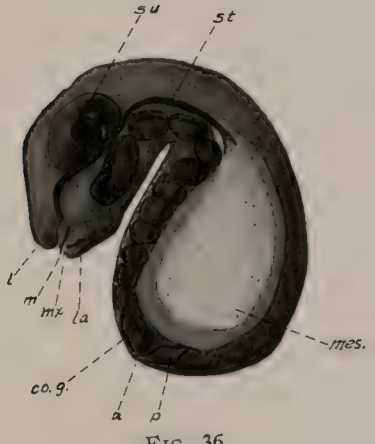


FIG. 36

BULLETIN

OF THE

ILLINOIS STATE LABORATORY

OF

NATURAL HISTORY

URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. JUNE, 1913 ARTICLE X.

STUDIES ON THE BIOLOGY OF THE UPPER ILLINOIS RIVER

BY

STEPHEN A. FORBES AND R. E. RICHARDSON, A.M.

ARTICLE X.—*Studies on the Biology of the Upper Illinois River.*
By STEPHEN A. FORBES AND R. E. RICHARDSON.

The Illinois River is peculiarly characteristic of the State of Illinois, and, next to the prairies, was its leading natural feature. The level richness of the central plateau of the state is reflected in the turbid waters and the broad sluggish current of the stream; and its wide bottom-lands, originally covered with huge trees, completely flooded when the river is highest, and holding many marshes and shallow lakes at its lowest stages, are a relic of the time, not so very far remote, when the limpid waters of the Great Lakes rolled down its valley in a mighty flood on their course to the southern gulf. It was not an accident that this river was the first great artery of transportation into and through the state, or that the first colonial settlement and the first fortified post in Illinois were established on its banks. After the railroads had deprived it of its commerce it was discredited and neglected for many years, and the second city in the country and the second city of the state have long used it as a mere convenience for the discharge of their organic wastes.

These are temporary conditions, however, and the time seems now at hand when the people of Illinois will learn to appreciate and develop this great gift of nature in the various directions in which it may be made to serve their interests and their pleasures. Its frequently beautiful and occasionally picturesque scenery is attracting more attention every year; and when, as is sure to happen in due time, a superior highway follows its course between Chicago and St. Louis; when the attractive building sites on its banks are relieved, as they now might generally be, from the midsummer plague of mosquitoes; when its most interesting situations are converted into public parks, and its fisheries are protected and enriched by means of state reservations for the breeding and feeding of fishes; and when, as must eventually come to pass, it becomes once more an indispensable central link in a principal line of traffic between the Great Lakes and the Gulf,—it will take for all time, for the state at large, the place which Lake Michigan now holds for our greatest city.

The senior author of this report began work, as a biologist, on Illinois River problems, some thirty-six years ago; and the junior author has virtually lived on the river for purposes of investigation during the last four years. The Natural History Survey of the state

has published in the meantime more than twenty-five hundred pages of contributions to its biology; and it is now rounding this work to a close, and bringing its results to bear, in practical ways, upon the economic problems most pressing and important at the present time. The paper here presented is intended as a preliminary summary only of the principal conclusions, scientific and economic, to be drawn from our studies of the last few years, and it is to be followed presently by a series of special papers on the various divisions of the investigation.

Acknowledgments

Our grateful acknowledgments are due to the U. S. Bureau of Fisheries for financial assistance in carrying out a fairly adequate program of field work in 1911 and 1912; to the Illinois State Fish Commission for opportunities afforded us to obtain the plankton of the Illinois, Mississippi, and Ohio rivers on long steamer trips which we could not otherwise have made; to the Water Survey of the State, the director of which, Dr. Edward Bartow, has taken virtual charge of the chemical work here reported, and has provided, from his staff, experienced analysts who have made all our determinations of gases from the waters and from the river sediments; and to the directors of the Missouri Botanical Garden, in St. Louis, Dr. Wm. Trelease, succeeded by Dr. George T. Moore, who have placed the library, collections, and laboratory facilities of the garden at our disposal, and the latter of whom has given us also his personal assistance in determining the algæ of our river collections.

Objects of the Investigation

The Illinois River work of the Natural History Survey, pursued at irregular intervals since 1877, became virtually continuous at Havana for five years, from April, 1894, to March, 1899, after which it seemed expedient, first to diminish, and in 1903 to suspend, field operations in order that our more important scientific results might be organized, reported, and published. This end being largely accomplished by voluminous papers printed in volumes IV, V, VI, and VIII of the Bulletin of the State Laboratory of Natural History, and by the publication also, in 1908, of an elaborate report on the fishes of the state, active field work on the river problems was resumed in July, 1909.

The opening of the Chicago Drainage Canal in 1900 was a revolutionary event in the biological history of the river; and as the

most important period of our earlier work was that immediately preceding this event, an examination of its consequences to the general system of aquatic plant and animal life was an important part of our object in recommencing systematic study. As the Illinois is a rather peculiar member of the great Mississippi River system, it was also much to be desired that comparative studies should be made on the life of the more closely related companion streams; and as the Illinois is economically one of the most productive rivers in the United States, it was evidently time to study the subject of the conservation and possible increase of its values in the light of the knowledge we had gained, and intended to gain, of its physical, chemical, and biological conditions and requirements.

The economic problem seemed especially urgent because of the great changes in progress at the time in the environment of the river, and the still greater changes impending, which were certain to affect greatly and permanently its value for the purposes which it had previously served. Reclamation projects, for the protection, drainage, and cultivation of its bottom-lands; manufacturing projects, threatening various contaminations of its waters; canalization project; and projects for the control of its flow in the interests of transportation, were all being earnestly agitated, and some of them were in course of active development. It is true that these changes are both inevitable and desirable, in view of all the interests involved; but it becomes all the more imperative to learn as promptly as possible what their effects have been and are likely to be, in order that practical correctives may be applied where necessary, to the end that a *modus vivendi* may be found which will take all these interests into full account, and make sure that nothing is needlessly sacrificed in the course of the use and development of the stream.

The reports of the work of the earlier period were largely on the minute plant and animal life of the stream—its so-called plankton—which forms a considerable part of the food of many kinds of fishes and nearly all the food of the young of almost every kind; and the plankton product of the waters of the Illinois under the new conditions, as compared with those prevailing before the opening of the sanitary canal, was one of the first topics to commend itself to us for careful study. Involved in this subject of food production for fishes, river mussels, and other useful aquatic animals, was the economic effect of a great increase in the flow of the stream, the rise in its levels, and the consequent expansion and longer continuance of its overflows, which there was some reason to suppose might so increase the food supply and enlarge the breeding and feeding grounds

of fishes as to increase the fisheries products of the stream. It was also a matter of interest and importance to learn the effects, both direct and indirect, of the increased inflow of sewage by way of the sanitary canal and the Des Plaines, upon the fishes and mollusks of the Illinois—an inquiry calling for chemical examinations of the waters of the stream and systematic collections from it at various points on its course, under various conditions, and at different times of the year.

Character and Chronology of Field Operations

The work planned upon these lines has taken three directions: the first year was given mainly to a study of the plankton of the river and of the principal bottom-land lakes, made on the same grounds and by the same methods and equipment as those of the period from 1894-1899; the second year was devoted especially to chemical determinations of the gases of the waters and of the bottom sediments of the upper river, from its origin to Chillicothe, and to parallel collections of the minuter plankton—the so-called microplankton—of the stream made at the same times and places as the chemical studies; and in the third year, similar chemical and biological determinations were made, with principal attention, however, to fishes and mussels and to the other plant and animal life of the bottom and the shores.

Advantage has also been taken of opportunities given us by the State Fish Commission to collect the plankton of the Mississippi and Ohio rivers for comparison with that of the Illinois, and especially to study the effect of protracted drouth and continuous low water on plankton production in the streams themselves. Much time was given during the spring seasons of 1910 and 1911 to field studies of the habits of spawning fishes and the times and places where their eggs were laid, and to the fate of the eggs and the rate of growth of the fry. These observations were intended especially to give us a better knowledge of the proper limits of a closed season for the protection of the more valuable fishes, and to show us also what measures are necessary to keep the numbers of the young up to the limits set by the available food supply.*

The collection of materials for a comparative study of the plankton of our principal rivers was actually begun in 1902, when virtually continuous collections were made from the steamer "Illinois" of the

*For a summary of results, see Bull. Ill. State Lab. Nat. Hist., Vol. IX, articles VII and VIII, March, 1913.

State Fish Commission, beginning at Montezuma, on the lower Illinois River, going thence to Grafton, at its mouth, from Grafton up the Mississippi to Quincy, down that stream to St. Louis, from St. Louis back to Grafton, and thence up the Illinois to Pekin. The systematic plankton collections of this trip were the first ever made on the Mississippi River. Additional collections were obtained in 1902, by the use of the station launch, from Pekin to Peoria Narrows, and in August, 1903, from Wesley, below Peoria, to Henry, thirty-three miles above. The next long trip was made June 8-17, 1910, again on the steamer "Illinois," from Keokuk, Iowa, to Quincy and St. Louis, and thence up the Mississippi and the Illinois to La Salle, with a return to Havana; and additional materials for a study of the plankton were obtained by means of numerous collections in Peoria Lake, July 19-22 of this year. The final trip of the series was made with the "Illinois" July 25 to August 6, from Havana down the Illinois and the Mississippi to Cairo, and thence up the Ohio to Paducah, Ky., where we left the steamer, to rejoin it at St. Louis for continuous collections up the Mississippi and the Illinois to La Salle, and back to Havana.

In 1911, chemical determinations and biological collections for an analysis of seasonal conditions on the upper Illinois and in related waters, were begun July 18 and repeated at frequent intervals until the 13th of December. Similar trips were made in February and March, 1912, for a study of winter conditions; and in July, 1912, an elaborate series of oxygen determinations was made for the entire length of the river. August 21 to October 12, two such series were obtained for the upper Illinois; and in November two more, for the whole stream, with comparative tests for the Mississippi, below and above the mouth of the Illinois. The situations thus brought more or less closely into comparison were the sanitary canal at Lockport, the Des Plaines River at the same place and at its mouth (Dresden Heights), the Kankakee just above its mouth, and the Illinois River at Dresden Heights, Morris, Marseilles (both above and below the dam which crosses the river there), Ottawa, Starved Rock, Peru, Hennepin, and Chillicothe. The distances of these points from the mouth of the Chicago River are approximately as follows, in miles: Lockport, 35; Dresden Heights, 53; Morris, 62; Marseilles, 80; Ottawa, 86; Starved Rock, 95; Peru, 102; Hennepin, 116; and Chillicothe, 145, ninety-two miles of this last-mentioned distance being on the Illinois River itself.

In 1911, low-water midsummer conditions were shown by studies pursued between July 15 and August 29, during which time three

successive trips were made, the first from Lake Michigan and Lockport to Chillicothe, and the other two from Dresden Heights to the last-named point. Early autumnal conditions were studied from Lockport to Chillicothe at various dates in September; late autumnal conditions between the same points, November 1-10; and winter conditions at Morris and Marseilles, November 30 to December 3.

On this last visit the collection of fishes from the more contaminated parts of the stream was first attempted by means of seines. Observations on fishes had, however, been made at various points from the beginning of operations in July.

From the 16th to the 28th of February, 1912, efforts were persistently repeated at Morris to obtain fishes from the river by the use of seines and fyke-nets, and by the explosion of dynamite. Oxygen determinations were secured at this time from all the usual points between Lockport and Chillicothe, as well as from the Kankakee above Dresden Heights; and the following month (March 18-28) a full series of such determinations was made the whole length of the river from Morris to Grafton, from the Des Plaines and the sanitary canal at Lockport, and from the Mississippi above the mouth of the Illinois. It was the object of this series to give us the data for a comparison of extreme seasonal conditions throughout the course of the stream.

Lack of funds prevented a resumption of our biological river work in the spring of 1912; but the new appropriations of the Natural History Survey, available July 1, fortified by an allowance from the U. S. Bureau of Fisheries, enabled us to resume the collection of chemical and biological data August 1, and to continue it without intermission until October 25.

In this time the chemistry and biology of the situation was studied, on two successive trips, at each point from Lockport to Chillicothe, collections of plants and animals being obtained with dip-nets, large and small seines, trammel-nets, set-nets, dredges, and the mussel-bar, and by the explosion of half-pound cartridges of dynamite, and oxygen ratios being determined for each place and time at which the biological data were obtained.

Finally, in March, 1913, samples of the bottom sediments were collected from all the five Illinois River dams, and from some other points in the main channel, for physical and chemical examination, with a view to ascertaining the condition of the river bottom when the river water has been for some months at or near the freezing point.

Importance of the Plankton

The economic importance of the plankton is largely in the predominance of these minute animals and plants in the food of the young of our most important fishes,—a predominance which may be expressed, without serious exaggeration, in the aphorism: no plankton, no fish. Furthermore, adults of many useful species, the crappies and the sunfishes, for example, often cram their stomachs with plankton organisms when these are especially abundant, as in spring. The youngest fishes and adults differ, however, as a rule, in their mode of obtaining this kind of food, the latter straining it out of the water by means of their gill-rakers and the former capturing the minute animals one by one, as full-grown predaceous fishes capture their larger prey. There is, indeed, an important exception to be made to the foregoing too sweeping statement. The young of the sucker family seem to take their earliest food much as do the adults—by sucking it up from the bottom—and while many plankton organisms are caught by them in this way, these are largely forms which commonly live on or near the bottom, the free-swimming species (*Daphnia, Cyclops,* and the like) being commonly scarce in the food of this family. The young of some other species also feed habitually near the bottom, so that the bottom-loving plankton organisms are represented in their food in disproportionate numbers as compared with the average product of the plankton net. Nevertheless, conditions which bring about an abundance of true-floating or free-swimming plankton, have, generally speaking, a like effect on the more significant part of the minute bottom-life of our waters generally, and the yield of the collector's net is thus a fairly reliable index to the food supply of young fishes, of whatever habit. It is true that these, as a rule, make little use of the plants of the plankton as compared with its animals, and that the numbers of the two often do not vary together; but if we remember that the plankton animals themselves feed largely on microscopic plants, we shall see that the latter are indirectly useful to fishes, even when not directly so.

Changes in River Levels

It follows from the foregoing discussion that one of the important points to be determined in our earlier operations of 1909 and 1910 was the effect on the plankton content of the Illinois River and its connected waters traceable to the opening of the Chicago

Drainage Canal, and to the increase in the volume of the stream and in the extent and continuance of its overflow consequent upon that event.

Something of the magnitude of this increase may be inferred from a comparison of the river-gage readings at Havana or below Copperas Creek dam for two ten-year periods preceding the opening of the canal (on January 17, 1900) and the ten years immediately following. The period from 1880-1889 inclusive was characterized by relatively high water, with an average of 7.4 feet above the low-water base-line of 1879; the second, from 1890-1899, was a low-water period, with an average gage reading of 6.32 feet; and the third or last period of ten years, from 1900-1909, was a maximum period, with an average of 9.72 feet. Taking these last two periods into comparison, separated, as they are, by the opening of the sanitary canal, we find a difference of 3.4 feet of average level, attributable in great part to the access of canal waters. There was, however, an apparent difference between these two periods in the rainfall of the upper Illinois basin amounting to 1.9 inches, which may be held to account for a part of the average high water of the later one.

The River Plankton

Our Havana plankton collections were made in series, at sufficiently frequent intervals between August 30, 1909, and August 29, 1910, from three localities—the Illinois River, Thompson's Lake, and Quiver Lake. Forty collections were made in this period from the river, forty from Quiver Lake, and thirty-nine from Thompson's, distributed as follows by months: 1909—August, 1 collection; September, 4 collections; October, 4; November, 5; December, 2. 1910—January, 1; February, 1; March, 2; April, 4; May, 4; June, 3; July, 5; August, 4. In December only one collection was made from Thompson's Lake.

The average plankton product of the Illinois River for each month of this year (August, 1909, to August, 1910), stated in cubic centimeters of plankton to one cubic meter of water,* is shown in the following table, together with corresponding monthly averages for the three years from September, 1895, to August, 1898, inclusive.

*Equivalent, of course, to parts per million *by volume*.

ILLINOIS RIVER PLANKTON, MAIN STREAM AT HAVANA, ILL., 1895-'98 AND 1909-'10. GIVEN IN CUBIC CENTIMETERS OF PLANKTON TO ONE CUBIC METER OF WATER

	'95-'96	'96-'97	'97-'98	'09-'10
September	1.52	.38	6.33	.10
October	.57	1.10	5.94	2.58
November	3.02	.02	1.	1.38
December	1.19	.76	.56	.38
January	.01		.45	.01
February	.01	.04	.27	.21
March	.07	.38	.33	2.18
April	5.69	5.11	4.40	29.60
May	1.30	5.62	11.30	12.27
June	.71	.27	3.96	11.89
July	1.44	4.78	.58	.23
August	1.17	3.65	.91	.06
Averages	1.39	2.10	3.	5.07

These are the only years of the earlier collecting period for which our data are sufficiently continuous to serve the purpose of a comparison. The general average of monthly averages for the year 1909-'10, it will be seen, was 5.07 cm., those for the earlier years being, respectively, 1.39, 2.10, and 3.

From a scrutiny of the columns of figures of these three years in comparison with the column for 1909-'10, it becomes evident that the series of monthly plankton products for 1897-'98 has much the closest resemblance to that of 1909-'10, and that this is the year that must be chosen for our comparison, so far as the data of average plankton production are concerned.

If the figures of the following table of gage readings be compared in the same manner and for the same purpose, it will be seen that the series for 1897-'98 resembles 1909-'10 more closely than any one of the four years of the earlier period of this table, the principal difference being in the autumnal months, when plankton production is relatively small at best and is of comparatively little significance as an item of fish food.

MONTHLY MEANS OF GAGE READINGS
ILLINOIS RIVER, HAVANA

	'96-'97	'97-'98	'98-'99	'99-'00	'09-'10
September	4.62	2.01	4.44	2.63	8.01
October	6.04	2.01	4.26	2.99	7.37
November	5.89	2.82	7.44	3.88	8.94
December	5.48	3.22	6.59	4.74	11.45
January	11.28	5.08	7.99	5.83	6.98
February	11.13	8.94	7.02	9.39	8.71
March	13.89	12.99	13.05	14.33	12.63
April	13.40	14.	11.15	13.44	12.28
May	9.41	11.55	8.02	9.52	13.98
June	5.54	11.53	7.80	7.61	12.14
July	6.05	5.70	4.38	5.94	11.02
August	2.29	3.66	3.20	6.36	8.76
Averages	7.92	6.96	7.11	7.22	10.19

We have thus two reasons for making the year 1897-98 the basis of our comparison of plankton production before and after the opening of the drainage canal; and as that for the former year is 3 centimeters per cubic meter and for the latter is 5.07 centimeters, we have sufficient reason for concluding that the plankton production of the stream has been largely increased per unit of volume as a consequence of the opening of the drainage canal, and that, so far as the evidence goes, the ratio of the present yield to the former is at least as 5 to 3.

Remembering further that the most important plankton product is that of the spring months, when young fishes are hatching from the egg and are dependent upon the plankton organisms for their earliest growth as fry, we find a special significance in the fact that the plankton yield of the river for the months of March, April, May, and June, was 2.85 times as great in 1910 as it was in 1898; or, if we omit the month of June as rather late for this purpose, the yield of the former year, March to May, is still 2.12 times that of the latter year. Taking for our comparison all the plankton averages for March, April, and May in all the years from 1894 to 1899, we find that the yield of these months in 1910, averages 4.29 times that of the same months of the earlier period.

From these various points of view, therefore, we are compelled to infer a much larger plankton yield to the cubic meter of water in the Illinois River itself at Havana during the year September,

1909, to September, 1910, than in any year of our collection period preceding the opening of the drainage canal. As the river contains, generally speaking, a mixture of contributions from all its tributary waters, the quantities of its plankton, particularly during the spring months when these waters communicate with it most freely, are the best obtainable index to plankton production in the whole system of streams and lakes whose surplus water it carries away. Nevertheless, a comparative study of conditions in two highly typical bottom-land lakes, so made as to show the effects in them of a change to the new and higher water-level, will have its special interest, particularly as it is in these bottom-land backwaters that most of the fish fry are hatched, and spend, as a rule, the first weeks of their existence.

The Lake Plankton

Thompson's Lake.—Thompson's Lake is a typical, permanent bottom-land lake, continuously connected with the river at all stages of water. In the higher stages the land between it and the main stream is completely overflowed; at medium stages the river water enters at its upper end and flows out from its lower; but at the lowest levels the lake is connected with the stream only by a narrow creek-like outlet at its upper end. At six feet above "low water" it covers nearly 3000 acres; and at a river level of nine feet its area is about 4300 acres.*

As will be seen from the following table, the plankton series of Thompson's Lake for 1909-10 does not closely resemble any one of the series of the earlier years, although the latter part of it, from February to August, 1910, is quite similar to the corresponding part of the record for 1897-98.

*Tabulation of Areas of Thompson Lake for the Various Water Elevations. Report of the Submerged and Shore Lands Legislative Investigating Committee (Forty-seventh General Assembly), Vol. I, p. 171.

PLANKTON OF THOMPSON'S LAKE, 1894-99 AND 1909-10
CUBIC CENTIMETERS TO THE CUBIC METER

	'94-'95	'95-'96	'96-'97	'97-'98	'98-'99	'09-'10
September	6.40	3.58	4.19	10.	2.65	3.34
October		3.15	2.81	35.35	1.24	3.54
November		5.07	2.66	16.67	1.17	8.25
December	1.29	1.	2.56	5.95	3.58	13.04
January		2.51		.46	2.46	2.28
February		2.58	.27	.24	1.58	.70
March		10.26	.65	.05	.21	.44
April	28.20	16.97	10.38	2.80		2.93
May	61.44	23.11	7.88	25.94		31.56
June	9.42	24.92	3.59	10.43		16.24
July	4.82	10.74	3.31	2.08		4.88
August	3.09	1.08	19.40	2.63		6.07
Averages		8.75	5.25	9.39		7.77

Averages for March, April, and May:
1895–96 to 1897–98 10.89
1909–10 11.68

Comparing the two years for these three months only, we find the plankton average for 1897-98 to be 6.31 cubic centimeters, and that for 1909-10 to be 8.97 cubic centimeters. If, however, we compare the average for these two years entire, the yield for the former year is 9.39 and that for the latter is 7.77. If, on the other hand, we take for comparison the plankton yields for March, April, and May of all three years, from September, 1895, to August, 1898, inclusive, we find these to average 10.89 cubic centimeters as compared with 11.68 for the year 1909-10. It would appear, consequently, that there is no notable change to be made out in the productivity of the waters of the lake per unit of volume, as compared with the period preceding the opening of the drainage canal. It is to be noted, however, that the very much greater average area of this lake under present conditions, and the much larger, freer, and more continuous contributions to the river made by it at the higher levels must, of course, be taken into account in any discussion of the causes of the much richer plankton of the river itself.

Quiver Lake.—Quiver Lake, at stages low enough to separate it from the main stream, is a mere broad bay of the Illinois, opening widely at its lower end, receiving the waters of Quiver Creek above, and fed in part by many springs along its high, steep, and sandy eastern bank. It was formerly clogged with vegetation in midsum-

mer and in fall, except when occasional floods would sweep it clean for a time; but since the drainage canal was opened its character is completely changed, and there is now but little vegetable growth to be seen in it at any time of the year. It is also, of course, now considerably larger and much more freely connected with the river than before, and the lowlands separating it from the stream are much longer under water.

PLANKTON OF QUIVER LAKE, 1895-99 AND 1909-10
CUBIC CENTIMETERS TO THE CUBIC METER

	'95-'96	'96-'97	'97-'98	'09-'10
September	.94	.31	.16	1.16
October	.13	2.10	.04	.65
November	.05	.24	.09	7.16
December	.46	.91	.006	1.20
January	.03		.021	1.17
February	1.75	.19	.30	.60
March	1.85	.34	.74	3.18
April	12.12	13.38	.53	38.26
May	2.99	1.29	16.24	13.
June	1.26	1.26	2.22	3.14
July	.29	.89	.16	1.04
August	2.46	.20	1.66	2.80
Averages	2.03	1.92	1.85	6.13

Averages for March, April, and May:
1895-'96 to 1897-'98 5.50
1909-'10 16.15

Consistently with these facts its plankton content per cubic meter is very much greater than formerly, in whatever way the ratios may be figured. Its average for the year 1909-10 is 6.13 centimeters per cubic meter, while the highest average of any one of the three earlier years was 2.03, and the general average for the three years was 1.93. The present yield is thus more than five times that of the former period. If we take into account the spring months only (March, April, and May), the average yield for the three earlier years was 5.5 centimeters, and for 1909-10 it is 16.15—virtually a threefold increase at this most important season.

RIVER AND LAKES COMPARED

That a great change has been produced in the relative productivity of the river and the lakes is evident from the following table of the average yield of plankton per cubic meter of these three waters.

	River	Quiver Lake	Thompson's Lake
1895 & '96 to 1897 & '98	2.16	1.93	7.80
1909 & '10	5.07	6.13	7.77

In the three full years of the earlier period whose data are used in this discussion, the plankton of Quiver Lake water was lowest, that of the river was but little higher, and that of Thompson's Lake was three and a half times the latter. In 1909-10 the yield of the river was lowest, that of Quiver Lake was 21 per cent. larger, and Thompson's Lake yielded 27 per cent. more than Quiver, the change being due to a great increase in the river yield and a still greater increase in that of Quiver Lake, while the yield of Thompson's Lake remained substantially unchanged.

If to these facts concerning the increase, in recent years, in the percentage of plankton contained in the waters of the Illinois, we add those concerning an increase in the average volume and area of the waters themselves, we shall see that their total plankton product must have been many times multiplied, and that the fisheries of the stream should feel the effects of this greater abundance of this important element of fish food; provided, it must be added, that the plankton supply is really at any time a limiting element in the production of fishes, such that we may amend the aphorism given on another page, to the form: "The more plankton, the more fish." It will, however, be a long time, in the writers' judgment, before the whole economy of fish production in our streams is so thoroughly understood that such a statement will be warranted. At present we can only say that there was produced in the waters and backwaters of the Illinois, in 1909-1910, an available and accessible amount of fish food sufficient for a much greater population of fishes than the stream had previously supported, and that if no such population is maintained, the reasons for the fact must be sought in some other direction.

Causes of an Increased Plankton

No change has recently occurred in the Illinois River system, or in the basin of the Illinois, to account for the increased productivity of its waters except the one already repeatedly referred to—the opening of the sanitary canal connecting the Illinois and the Chicago rivers at the beginning of 1900. The effects of this occurrence on the plant and animal products of the stream may conceivably have been produced in one or more of these three principal methods: (*a*)

by a mere increase of the waters themselves, which, in so sluggish a stream as the Illinois, with bottom-lands so extensive and so widely overflowed by so small a rise of the river levels, will take effect mainly in great expansions of shallow water, long continued or permanently maintained, with muddy bottoms and more or less weedy shores—situations quite capable of producing a relatively enormous plankton as well as an abundant supply of shore and bottom animals and plants; (*b*) by the addition of increased quantities of organic matter to the contents of the stream in the form of a larger inflow of sewage from Chicago and its suburbs, in condition to increase the plankton by increasing the supply of food available to the minute organisms which compose it; and (*c*) by the addition to the plankton of the river, of that of Lake Michigan brought down in the waters of the canal.

The efficacy of the first of these conditions is undoubted, as has been already shown, and that of the second is, generally speaking, quite possible. The importance of an abundance of organic matter in the water as a means of producing a rich plankton is, in fact, so well known that growers of pond fishes in Europe deliberately manure their ponds to increase the supply of food for their fish; and there is considerable evidence, also, that the plankton of the Elbe is largely increased by the sewage of Hamburg and Altona poured directly into that stream. Whether Chicago sewage has a like effect in the Illinois, and whether, if it has, that effect may not have disappeared before the waters of the stream have reached Havana, are problems which will be taken up in a later paper. The supposition that the waters of the canal may bring to the Illinois a richer plankton than that of the river itself is negatived at once by the fact that Lake Michigan water is relatively poor in microscopic life, and hence must dilute the river plankton instead of increasing it; and by the further fact that most of the characteristic minute organisms of the lake have died out in the river before they reach Havana.*

ILLINOIS RIVER WORK OF 1911 AND 1912

The Illinois River, it will be remembered, is formed by a union, near Dresden Heights, of the uncontaminated Kankakee and the heavily polluted Des Plaines. The waters of these streams flow down

*A partial exception to this statement is found in the survival in the river of the lake diatom *Tabellaria flocculosa*, its increase after it passes the Morris-Marseilles ordeal, and its immense multiplication in Peoria Lake. This species was not found in the Illinois before the opening of the drainage canal.

the larger river, the Des Plaines water on the north side and that of the Kankakee on the south, and are not completely mingled until the first dam is reached, at Marseilles, twenty-six miles below. They are less distinct, however, than they would be if it were not for an unfinished dam at Dresden Heights, which acts as a wing-dam to concentrate and hasten the current of the Des Plaines, throwing it with some force towards the other side of the Illinois, thus artificially mixing, to some extent, the waters of the Kankakee and the Des Plaines at their junction. These continue sufficiently separate, however, as far down as Morris, nine miles below the junction, to make a notable difference in contamination between the two sides of the stream.

The effect of the dam at Marseilles is to check the current above sufficiently to permit a considerable precipitation of suspended matter, which accumulates there in a deep bed of more or less putrid sludge. In going over the dam the water is thoroughly mixed and aerated, and the softer masses suspended in it are pulverized, and thus made ready for more rapid decomposition.

Between Dresden Heights and Morris the waters of the Illinois are slightly diluted by contributions from the Au Sable on the north and Mazon Creek on the south. At Ottawa, the Fox River comes in from the north—a stream a hundred and fifty miles long with an estimated low-water discharge of about two hundred and forty cubic feet per second.* On the southern side is the Vermilion, ninety miles long, emptying opposite La Salle.

These are the only tributaries of the upper river of sufficient importance to be noticed as influencing sensibly chemical or biological conditions in the main stream. A cluster of bottom-land lakes of some importance is found above Hennepin, and Senachewine Lake has its outlet into the river between that town and Henry. At the latter point is a dam which repeats, to some extent, the effects of the upper dam, at Marseilles. Chillicothe, which was the lower limit of most of our operations, is at the upper end of that expansion of the Illinois known as Peoria Lake.

The Microplankton, Summer of 1911

Three successive rounds were made in the summer of 1911 to the selected list of stations between Dresden Heights and Chillicothe, by a chemist (Mr. Charles H. Spaulding) and a biologist (the junior

*Chemical and Biological Survey of the Waters of Illinois, Report for 1911, p. 162.

author) working conjointly. The first trip was made July 18 to August 4; the second, August 10-17; and the third, August 21-29.

The weather of July and August, 1911, was unusually dry and hot, with the river continuously at very low level. A rain of about a quarter of an inch fell July 20, in the upper Illinois valley, but this had no perceptible effect on the river. Upwards of an inch of rainfall August 10, followed by a rise of about six inches in the Kankakee, also brought the Illinois up in the Morris-Marseilles section, and the August stage of water was throughout a little higher than that of July.

In collecting from the waters of the flowing stream, all samples were taken within eighteen inches of the surface, by means of a liter-bottle opening and closing mechanically. On the return from the field the contents of each liter flask were thoroughly shaken together and 50 cubic centimeters were drawn off with a pipette and reduced to 10 centimeters by straining through No. 575 S. & S. hard-pressed filter-paper. After this condensed sample was thoroughly shaken, a Rafter cell holding one cubic centimeter was filled, and counts of the *living* plankton were made under a microscope by the methods usually employed in preserved specimens. The above method of collection is a slight modification of that recently used by Kolkwitz,* differing from it chiefly in the fact that the samples were condensed before examination. The fundamental feature is the direct field examination and enumeration of the living organisms in small samples, which in the practice of Kolkwitz were not strained or condensed in any manner.

This concentration process seemed to us to be called for to insure a number of organisms in the samples examined, sufficient to give a dependable count. The correctness of the method used is, in our opinion, fairly attested by the general consistency and reasonableness of the figures obtained, if proper account is taken of the known variability of hydrographic and chemical factors. A few special tests of it were nevertheless made. (*a*) Duplicate counts of collections from the same place on the same day showed neglible differences only. (*b*) A collection obtained at Chillicothe August 17, containing a total of 162 organisms per cubic centimeter (not counting bacteria,) was filtered, and a centimeter of the filtrate was found to contain no organisms except a few bacteria. (*c*) A collection from Depue Lake containing 40,000 chlamydomonads per centimeter was filtered, and the filtrate contained only 147 green monads

*Mitth. aus der Kgl. Preuss.-Anstalt für Wasserversorg. und Abwasserbeseitigung zu Berlin, 1907.

per centimeter, a residue of .3 of one per cent. which had escaped through the filter-paper. (*d*) A Fox River collection made September 2, containing 3161 organisms per cubic centimeter, yielded in the filtrate 12.6 organisms per centimeter, less than .4 of one per cent.

There was, of course, always some undeterminable loss through adhesion to the filter-paper, but this was minimized by the large amount filtered (50 cubic centimeters), and by thorough washing of the filter during the removal of the 10-centimeter residue. To all appearance the loss was very slight, and, the error being practically uniform since the same methods were used throughout, it could not invalidate comparisons.

Definition of Terms.—As a considerable part of this paper will be given to a description of the criteria and effects of different degrees of contamination of the natural waters of the Illinois, we will distinguish, as clearly as convenient, three stages of impurity, by the use of the following terms applicable both to the waters themselves and to the characteristic organisms, given here in the order of a diminishing impurity, namely, (1) septic or saprobic, (2) polluted or pollutional, and (3) contaminated or contaminate; and to these we will add "clean water" to indicate the conditions and organisms substantially equivalent to those of the natural, uncontaminated stream. These expressions seem sufficiently definite and significant to distinguish between stages which at best can not be sharply marked off; and we prefer them for our purposes to the equivalent highly technical terms polysaprobic, mesosaprobic α, mesosaprobic β, and oligosaprobic, introduced by Kolkwitz and Marsson.

Only a very general account of the product of these collections will be given at this time, the subject being reserved for more detailed report in a later paper.

For a merely general and preliminary presentation of our data of 1911 relating to the midsummer microplankton of the upper Illinois, we may conveniently divide the waters from which our collections were made into four sections or general situations, corresponding to distinguishable stages of pollution and self-purification; (1) the sanitary canal at Lockport, (2) the Des Plaines River at Dresden Heights and the Illinois River from that point to Marseilles, and (3) the Illinois River from Marseilles to Starved Rock, and (4) from Starved Rock to Lockport.

In the sanitary canal at Lockport we found, in September, 1911, an abundant Lake Michigan plankton with little admixture of septic organisms. It was largely composed of characteristic lake diatoms

and flagellate *Protozoa* of the *Chlamydomonas* type, still living and in process of multiplication,— a fact easily understood, in view of the recent origin of the water in the lake and its undisturbed flow and relatively low temperature in the deep canal.

The Des Plaines River at this point was heavily loaded with sewage wastes derived partly from the sanitary canal, which sends into it an overflow through the turbine waste ditch of the controlling works, and at times also through the sluice and over the bear-trap dam at the same point. This stream was heavily contaminated also, in 1911, by sewage from several suburbs of Chicago on the Des Plaines above Lockport. As it was very low and the water spread in a thin sheet over a rocky bottom, its temperature was much higher than that of the canal, and septic organisms were at their maximum. The most conspicuous of these was the well-known "fungo-bacterium," *Sphærotilus natans*, a filamentous form which grows in long, loose, hanging tufts and branches in septic and polluted waters. The stony bottom of the Des Plaines between Lockport and Dresden Heights was carpeted with this plant, and with it were associated a considerable variety of *Protozoa* (*Carchesium lachmanni, Vorticella microstoma, Epistylis plicatilis, Oikomonas termo, Bodo saltans,* and *Paramecium putrinum,*) all characteristic foul-water species. These were continually being torn loose by the swift current of the lower Des Plaines and mixed with the free plankton, with which they were carried far down the stream, feeding and multiplying as they went, until a gradual purification of the water made it unfit for their maintenance.

The Illinois from Dresden Heights to Marseilles was, in July to September, 1911, an especially saprobic or septic section of the river, this condition culminating at Morris, if we may judge by the numbers of septic organisms in the plankton. The most abundant of these were *Sphærotilus natans*, detached filaments of which made about 90 per cent. of the number of the plankton organisms in this and the following section. These were most abundant at Dresden Heights, and were much more so at Morris than at any point below. Several of the larger species of saprobic bacteria, not essentially different in food requirements from *Sphærotilus natans*, were notably abundant in this section: *Bacterium vulgare*, *Spirillum volutans*, and species of *Streptococcus* were common examples. The largest collections of detached heads of the *Vorticellidæ* (*Carchesium lachmanni* and *Epistylis plicatilis*) were made at Dresden Heights and Morris. Flagellate, colorless *Protozoa* which feed upon bacteria, were also extremely abundant in this section. The largest numbers of *Oiko-*

monas termo were found at Marseilles above the dam, and the number at Morris and below the dam at Marseilles was much larger than at stations either above the former or below the latter point. It was further characteristic of this section that one-celled green algæ and green flagellate *Protozoa* were nearly absent in its waters except for survivors of the Lake Michigan contribution. Even the hardier Lake Michigan diatoms were distinctly waning in numbers, their moribund condition being plainly shown by the fading and breaking down of their chloroplasts. On the other hand, many diatoms come through this section alive, particularly the two species of *Tabellaria* (*fenestrata* and *flocculosa*) together with some of the Synedras and Naviculas.

The microplankton collections of the section from Marseilles to Starved Rock agree with the longshore collections to the effect that the septic organisms were diminishing rapidly here, *Sphærotilus* and *Carchesium* disappearing from both the waters and margins, but appearing in dredgings from the bottom of the channel, to which these organisms had seemingly settled to die. *Oikomonas termo* also, the most abundant bacterium-eating protozoan, gave us an average of 210 to the cubic centimeter above the dam at Marseilles, but fell to an average of 54 to the centimeter at Starved Rock. The Lake Michigan diatoms, on the other hand, continued in nearly constant numbers, as did also the clean-water unicellular algæ and green *Protozoa*.

In the Starved Rock-Chillicothe section of the river the outstanding feature of the plankton was the marked increase in diatoms and other chlorophyll-bearing unicellular organisms, plant and animal, which became sufficiently abundant by the time Hennepin was reached to give the water a characteristic greenish tinge. This was largely due, however, to the picking up numbers of a single species of diatom, *Melosira granulata* var. *spinosa*, a form common in the Illinois River and especially in its backwaters. This "greening up" of the water below La Salle was noticed, in fact, on a down-stream trip in June, 1910, and was conspicuous to the naked eye in both 1911 and 1912, most noticeably so at the lowest water-levels. Rise of water and an increased turbidity due to flooding rains in early August, 1911, obscured it for a time. It will presently be seen that these indications of a radical change about Hennepin in the biological contents of the water, are supported by the products of longshore collections, for it is here that the foul-water blue-green algæ began distinctly to diminish, that the Cladophoras and *Stigeoclonium lubricum* began to take the place of *Stigeoclonium tenue* as the most abundant green algæ,

and that the amphipod crustacean, *Hyalella knickerbockeri,* put in its first appearance below Dresden Heights.

The Sanitary Canal at Lockport

Our data for the sanitary canal were obtained at Lockport, three and a half miles above the lower locks through which the canal empties into the Des Plaines. They were derived from biological collections made at this point September 25, 26, and 27 and November 1, 1911, and August 9 and October 7, 1912; and from chemical determinations made November 1, 1911, and February 7, March 18, November 1, and November 13, 1912. The biological data thus represent the conditions of late summer and autumn, and the chemical data, those of autumn and winter, but neither apply directly to those of spring or midsummer.

General and Chemical Conditions.—At the time of the first visit, September 25, 1911, the water of the canal at Lockport was clear, like that of Lake Michigan, with much less silt and other suspended matter than the Des Plaines at the same point. It had a slight sewage odor, not particularly offensive; and there was no emission of bubbles of gas to indicate rapid fermentation or putrefaction of its contents. Miscellaneous offal and other refuse was floating or stranded along the edge of the canal, much of it but little decayed. In it were recognized grains of corn and wheat, melon seeds, tallow, pieces of entrails, bits of human excrement, pieces of old newspaper and toilet paper, fragments of finely chopped straw, and street sweepings. The grayish sludge at the bottom of the canal had a foul privy odor combined with a tarry smell like that of the sludge from the bottom of the Illinois River at Morris on the same date.

Under the colder weather conditions of November 1, 1911, with a surface temperature of the water at 50° F., the odor and general appearance were practically the same as in September. There was perhaps even less appearance of decay in the floating debris. Chicken entrails floating in the water of the canal looked, in some cases, almost fresh.

August 9 of the following year the color, odor, and general condition of the canal water were practically like that of September, 1911. The water temperature was 64 to 65 degrees F.; and the depth of the water in the canal was three to four feet above that of the fall of the preceding year.

The dissolving oxygen of the water, as shown by chemical tests, ranged from .4 of one part per million November 1, 1912, to 9.3

parts per million, February 17 of the same year. At the temperatures of the time, the first of these ratios was equivalent to 3.5 per cent. of oxygen saturation, and the last to 64.9 per cent. The average of the six observations made, was 4 parts of oxygen per million, or 31.9 per cent. of saturation. The general conditions were thus those of lake water rather heavily loaded with organic debris which had not yet undergone any great degree of putrefaction.

Plants and Animals.—Consistently with this statement, in September, 1911, a few small shiners (*Notropis atherinoides*) one to two inches long, were alive in the water, although in a dying state; but all the larger minnows of this species, together with many spottailed minnows (*N. hudsonius*), silvery minnows (*Hybognathus nuchalis*), and lake perch, were stranded, dead, along the shores. In the cooler weather of November, 1911, a larger proportion of the shiners were alive, and a single large fish, possibly a carp, was indistinctly seen moving away from the riprap at the north shore. All the fishes found, were common Lake Michigan species. A single frog was the only other vertebrate taken.

A cursory examination of the bottom sludge November 1, 1911, showed no signs of animal life; and the only insects seen in or on the water were a back-swimmer (*Notonecta*) and several waterboatmen (*Corixa*), both of which, as they breathe air, can afford to be indifferent to a deficiency of dissolved oxygen. No snails or crustaceans were found in the water at this place in either year. Along the riprap at the edge of the canal in 1912 was a mixture of normal and septic species of algæ, with others representing medium stages of contamination. The most abundant clean-water species were *Ulothrix zonata* and *Schizomeris leibleinii*, barely submerged on the riprap, where they were mixed with *Oscillatoria limosa*, to be classed as a contaminate species. There were occasional slight traces of *Sphærotilus natans* and *Beggiatoa alba*, both highly distinctive of septic or polluted waters, together with considerable growths of *Stigeoclonium tenue* (a contaminate form) and *Chlorella vulgaris*, the latter encrusting stones. Among the meshes of the marginal algæ were many septic *Protozoa* and rotifers (*Bodo saltans, Vorticella microstoma*, and *Rotifer actinurus*), together with others common in polluted waters (*Oikomonas termo, Monas vivipara*, and *Anthophysa vegetans*).

Des Plaines River, Lockport

September, 1911.—In late September of 1911 the Des Plaines at Lockport was much more offensive than the sanitary canal, its

organic contents being evidently in a far more advanced stage of decomposition. The stream was very low, flowing, at a depth of six inches to a foot, over stones and pebbles which were completely covered with a septic growth of *Sphærotilus* and algæ, mainly blue-green species. The water had a grayish look, and a filthy smell, which may perhaps be best described as a mixture of fishy and privy odors. The current was too swift to permit the deposit of much sediment; and it was frequently dislodging and carrying away fragments of the incrusting growth from the bottom. A comparison of the contents of the stream with those of the sanitary canal beside it pointed to the conclusion that the septic organisms of the upper Illinois were at this time being derived mainly from the Des Plaines and not from the canal, although the putrescible matter carried by the latter furnished an abundant nourishment for their growth and multiplication far down the course of the main river. The Des Plaines was a seed-bed, in short, and the canal water the soil, for the culture of sewage organisms in the Illinois.

Our collections from the river at Lockport were made opposite the Ninth Street Bridge, three miles and a half above the lower gates of the canal. *Sphærotilus natans* and *Anthophysa vegetans* were very abundant, with *Carchesium lachmanni, Epistylis plicatilis, Vorticella microstoma,* and *Paramecium caudatum* intermixed. Less distinctly septic forms were *Oscillatoria limosa* and *Stigeoclonium tenue*, with some *Ulothrix zonata.* Among tangles of dirty *Sphærotilus* were found large numbers of *Chironomus* larvæ, together with oligochæte and nematode worms. No fish were seen here in September, the water being evidently much too foul for even the most indifferent species.

November, 1911.—November 1, 1911, the stream was six to eight inches deeper, and the water temperature was 57° F., but conditions generally were not unlike those of September, except that the odor was less offensive. No snails or higher crustaceans could be found, although there were now great numbers of mosquito larvæ in the water. There were also many shiners (*Notropis atherinoides*), nearly all alive but mostly in a dying state, as if they had been carried down by the current from above, and overpowered by the toxic contents of the stream.

The content of dissolved oxygen was higher in the Des Plaines than in the sanitary canal—22 per cent. of saturation in the canal and 44 per cent. in the Des Plaines; and virtually the same relations were found again in November, 1912. February 2, 1912, on the other hand, the oxygen was nearly the same in both waters—9.3

parts per million in the canal, and 8.8 parts in the Des Plaines. The same was true March 18, when 6.3 parts of dissolved oxygen were found in the canal and 6.5 in the Des Plaines.

August and September, 1912.—Additional biological collections were made August 9 and September 30, 1912, with water temperatures at 67° F. on the first date and 64° on the second. The stream was rather low, with much vegetation, including water milfoil (*Myriophyllum*), *Elodea*, pondweed (*Potamogeton*), etc., the first two mainly on the west side. There was, in fact, a marked contrast at this time between the two sides of the river, due to the fact that the water of the east side was badly contaminated by a waste ditch flow from the sanitary canal, and contained there the sewage organisms noticed the preceding year. In the *Cladophora* of the west side were many live minnows, sunfish, etc., with *Spirogyra, Vaucheria*, duckweed, and epiphytic green algæ. Here also among the *Cladophora*, on the west shore, were numerous crustaceans—*Cyclops, Simocephalus*, and *Ostracoda*, together with *Hyalella dentata* and a single specimen of *Asellus*. On the east side there was an abundance of *Carchesium* on the stones, together with oligochæte worms (*Tubifex*) under mats of *Oscillatoria*. *Eristalis* and *Odontomyia* larvæ were taken in the contaminated water; and *Corixa* and *Zaitha* and larvæ of *Simulium* and caddis-flies among *Cladophora* on the west shore. The mollusks obtained were *Lymnæa humilis, Physa gryina*, and *Planorbis parvus* and *trivolvis;* the first on the east side and the others common on the opposite shore.

Des Plaines River at Dresden Heights

The midsummer condition of the mingled waters of the sanitary canal and of the Des Plaines at the mouth of the latter was shown by observations made at Dresden Heights, in July and August, 1911, where typical septic organisms predominated. From July 26 to August 1 this water had a grayish, sloppy appearance, with a mingled fish and privy odor. Sticks and stones were everywhere hung with tufts of two of the most abundant septic organisms, *Sphærotilus natans* and *Carchesium lachmanni*. These were being continually torn loose from their attachments and carried down stream, where they appeared abundantly in the plankton; and silt and other sedimentary matter was kept churned up in the current so that there was scarcely any accumulated sludge on the broken stones and boulders of the bottom and dam. The temperature of the surface layer of the water July 28 was 68° F. No fish could be found here

at this time, either dead or alive. It was here also that the largest number of septic organisms per cubic centimeter of water was obtained July 28 to August 3, by our modification of the Kolkwitz method,—186 per centimeter, as compared with 116 at Morris and 15 at Marseilles. Of the pollutional species, on the other hand, there were 55 per cubic centimeter at Dresden Heights as compared with 169 at Morris and 35 at Marseilles, while of the contaminate forms, there were 90 at Dresden Heights, 76 at Morris, and 28 at Marseilles. The mixed origin of the waters at this point was especially illustrated by the further fact that clean-water species averaged 209 per centimeter at Dresden Heights, 287 at Morris, and 270 at Marseilles. At Dresden Heights, however, these were almost wholly diatoms characteristic of Lake Michigan water, which had evidently been brought down by the sanitary canal. The most significant of these were two species of *Tabellaria*—*T. fenestrata* and *T. flocculosa* —together with *Fragilaria virescens* and *Cyclotella kützingiana*. The Tabellarias were never taken in our Illinois River plankton previous to the opening of the sanitary canal, and their maximum number in the Illinois in these 1911 collections came from above Marseilles. The other two species formerly occurred in both the river and lake, but they were rare below Morris in July and August of 1911—a strong indication of the Lake Michigan origin of those taken at Dresden Heights.

The water here July 27, at a temperature of 68° F., gave us an average of 13.1 per cent. of oxygen saturation as the mean of determinations made at 10 a. m. and 1:30 p. m., the Kankakee River giving us, on the other hand, just above the mouth, an average of 126.8 per cent. at 2 p. m., at a temperature of 71.6° F. In other words, the Kankakee, supersaturated with oxygen, contained nearly ten times as much as did the Des Plaines just above the junction point of these two rivers. The former held in solution, on the other hand, only one sixth as much carbon dioxide—2.1 parts per million to 12.8 parts in the Des Plaines. The oxygen content of the latter was practically the same September 26, 1912, as in the midsummer period of the preceding year, but increased greatly in fall, reaching 40.3 per cent. of saturation November 14 as compared with 11.2 per cent. September 26.

Biological conditions were but little changed in 1912, as shown by visits made in August and September of that year. As before, no fishes were found, and no other vertebrates except a single frog. Many dead shells of gastropod mollusks were seen, including *Planorbis trivolvis*, *Physa gyrina*, and *Lymnæa palustris*, and a single speci-

men of the last species was found alive among algæ in the drift. Numerous *Chironomus* eggs were in the same situation; and air-breathing beetles—*Dineutes* and *Gyrinus*—were also common, but there were no water-breathing larvæ except *Chironomus*. Slime worms (*Tubificidæ*) were rare in the soft black sludge at the bottom and the edge of the stream—a great contrast with conditions at Morris to be reported later. *Sphærotilus* was again very abundant on weeds and sticks, and on old stems of *Carchesium lachmanni*. Blue-green algæ, chiefly *Oscillatoria limosa* and *Phormidium uncinatum*, were fairly frequent. The green filamentous algæ, *Stigeoclonium tenue*, and *Spirogyra*, chiefly *S. vernata*, were common in both August and September, and *Ulothrix zonata* in the latter month; and some *Lemna* and *Wolffia* were caught in the drift along the bank. *Protozoa* were represented mainly by fixed forms, especially by *Carchesium*, attached to sticks or floating in the water. There were no sponges, hydroids, leeches, planarians, or crustaceans.

The general impression to be gained from these midsummer and autumn data is that of a heavily polluted stream with less oxygen and more carbon dioxide than was consistent with the life of fishes, mollusks, insect larvæ, or crustaceans, and with the natural fauna of the stream represented by saprobic organisms, except at its edges, where oxygen enough was absorbed from the air to serve the needs of a few green algæ and an insignificant group of associated animals. Decomposition of its sewage materials had not yet reached its climax, which came at Morris and Marseilles at low water in the hottest weather, and at various distances farther down when the water was higher or the weather cooler,—farthest, of course, when these conditions were coincident.

The Kankakee River at Dresden Heights

Conditions in the Kankakee at its mouth are particularly interesting and important since they give us a close approximation to those of the natural water of the Illinois River, derived, as they are, from a territory similar in character to the valley of the Illinois below, and contaminated but slightly, if at all at this place, by way of contributions from comparatively small towns at some distance above. Collections were made from the Kankakee at a point near the east bank and two hundred yards above the mouth of the stream. The samples were taken in two or three feet of water by wading out or by working from an improvised trestle forty feet in length. The river at this point is broad and shallow, with a moderately swift current, probably two to three and a half miles per hour, becoming

much quicker, however, as it approaches the rapids at the junction with the Des Plaines. The water was more or less yellow with clay silt. The color, odor, and the organisms obtained, were those of a clean and practically uncontaminated stream. The water temperatures at the surface were 69.7° F. July 24, 72.4° July 26, 82.5° August 9, and 73° August 21.

Nine determinations of oxygen were made on different dates,—July 24 and 26, August 10 (forenoon and afternoon), and August 21 (forenoon and afternoon), 1911; and February 19, September 26, and November 14, 1912. Four tests for carbon dioxide were also made—July 26, August 10, and August 21 (forenoon and afternoon), 1911. Six of the nine oxygen determinations showed that the water was supersaturated, percentages ranging from 104.6, September 26, to 133.1 on the afternoon of August 10. The lowest result was 62.2 per cent. of saturation on February 19. The general average of the nine determinations is 103.8. Forenoon and afternoon tests for the same day were made August 10 (10:30 a. m. and 2:30 p. m.) and August 21 (10:30 a. m. and 2 p. m.). Those for the forenoon averaged 101.7 per cent., and those for the afternoon 121.2 per cent. The afternoon increase was doubtless due to the liberation of oxygen by submerged plants under the influence of sunlight. The carbon dioxide found July 26 was 2.1 parts per million; August 10, .7 parts; and August 21, none.

The biological conditions were those of a clean stream, there being no plants or animals obtained here in either year commonly classed as saprobic—no blue-green algæ, no *Carchesium* or other fixed forms of *Protozoa,* no oligochæte worms, and no *Sphærotilus* or *Beggiatoa.* Green filamentous algæ—mostly *Cladophora glomerata,* with some *Microthamnion* and *Vaucheria*—many river mussels—the greater part of which were, however, for some unknown reason dead—and several water snails (*Goniobasis*), were among the commoner clean-water forms.

Illinois River at Morris

The water here was grayish, sloppy, and everywhere clouded with tufts of *Sphærotilus* and *Carchesium.* The odor was continuously foul, with a distinct privy smell in the hottest weather. Bubbles of gas were continually breaking at the surface from a soft bar of sludge formed along the north bank between Kindlespire's landing and the Mazon bridge. On the warmest days putrescent masses of soft, grayish black, mucky matter, from the diameter of a walnut to that of a milkpan, were floating on the surface. These masses,

held together by threads of algæ and fungi and growths of branching colonial bell-animalcules, rose from the bottom buoyed up by the gases developed within them, but settled quickly when they were broken apart by a light touch. Noticeably cleaner water, with a less offensive smell, carrying also much less *Sphærotilus* and *Carchesium,* was found along the south shore, where the Kankakee contribution still had a discernible influence. The water temperatures of the surface layer were 69.1° F. July 28, 73° August 11, and 73° August 23.

October 11, when the water was three feet higher than in August, conditions were greatly improved, the water being much less offensive in odor, with no bubbling of gases and no floating masses of detached sludge. The feathery tufts of *Sphærotilus* and *Carchesium* were also much less abundant. Virtually the same statement may be made for November 3, when the river level was about two feet above that of the midsummer season, and for November 13, when it was two or three feet higher still.

Imperfect Mixture of Waters.—A study of conditions at Morris was made difficult by the fact that the waters of various origin flowing past that point were not yet thoroughly mingled, those of the Kankakee predominating along the south bank and those of the Des Plaines River and the sanitary canal along the north bank, while the midstream current was made up of a variable mixture of the two. This was most plainly shown by a comparison of the chemical reports of the oxygen content of the water, on the same days but on opposite sides of the stream. Determinations of oxygen, available for this comparison, are as follows, stated in percentages of saturation.

Date	*North side*	*South Side*
September 13, 1911	9.70	21.40
September 27, 1912	17.90	37.40
November 2, 1912	41.40	56.00
November 14, 1912	54.60	73.10
February 17, 1912	45.80	52.85
March 19, 1912	65.40	73.80

The differences between the two sides of the stream varied with the weather and with the stage of water, being greater in hot weather than in cold, and greater also in high water than in low. In the former case the more rapid decomposition of the organic matter appropriated the oxygen more completely by the time the water of the northern side of the river had reached Morris. The degrees of

saturation with oxygen for the southern, or Kankakee, side were 113 per cent. larger in September, 1911, than those of the northern, or Des Plaines, side; 34.5 per cent. larger in November; and 13.9 per cent. larger in February and March, 1912. Flooding rains, on the other hand, tend to increase the difference and to carry it further down the stream. The clean Kankakee being a much larger river than the polluted Des Plaines, the effect of a strong rise in these streams is to increase the ratio of south-side unpolluted water to north-side polluted water, and to carry a larger volume of the former down to Morris and even to Marseilles, with less admixture than at low-water stages. This condition was illustrated by observations made November 3, 1911, when recent heavy rains had brought the river up about three feet. Midstream ratios, samples for which were taken from what was obviously Des Plaines River water, averaged 4.6 parts per million of oxygen, while south-shore samples (Kankakee water) contained 10.8 parts per million. The water temperature at this time was 41° F.

All our midstream samples were taken for analysis as near the center of the river as practicable, and usually from a depth of eighteen inches or two feet below the surface. Midstream ratios averaged 7.3 per cent. of saturation in July, 1911, 16.37 per cent. in August, 28.5 per cent. in November, and 48.76 per cent. in February, 1912. In September, 1912, they stood at 17.9 per cent., and November 14 at 57.2. This is the highest of our midstream readings; but a still higher one might have been obtained March 19, 1912, when even the north-shore ratio was 65.4 per cent., or 9.2 parts per million, with a temperature of 34.7° F.

Oxygen determinations were made on the same date from both sides and from the center of the river on only three days—February 16, September 27, and November 14, 1912. On these days the midstream percentages were much nearer to those of the northern or heavily polluted side than to those of the southern or lightly contaminated side, the mean difference being 3.7 per cent. in the first case and 48.4 per cent. in the second. In this we may probably see the effect of the wing-dam at the mouth of the Des Plaines in forcing the water of that stream well across the Illinois, leaving a comparatively narrow strip of imperfectly mixed Kankakee water along the south bank.

Extreme Midsummer Conditions.—The lowest ratios of oxygen at Morris were those of July 22, 1911, when samples were collected from the middle of the stream and from the south bank only, the former at a depth of five feet, and the latter at three feet below the

surface and forty feet from the bank. The south-shore samples averaged .21 parts per million, which, at the temperatures of the time, was equivalent to 2.65 per cent. of saturation, the corresponding figures for the midstream samples being .267 parts per million, or 3.1 per cent. of saturation. The water temperatures on this date ranged from 66.7° F. at 10 a. m. to 77° at 1:30 p. m.

Midstream samples showed no increase of oxygen in the afternoon, the parts per million, July 22, being .30 at 10 a. m., .26 at 1:30 p. m., and .24 at 4 p. m.; but those taken forty feet from the south bank were .04, .28, and .31 for the same hours, respectively.

The effects of sewage contamination are clearly shown by a comparison of these data with the Kankakee determinations of July 24 and 26, both made at 2 p. m., which stand at 9.91 parts per million for the first date, and 11.21 parts for the second—equivalent to 107.9 and 126.8 saturation percentages, respectively. The means of the Morris determinations for afternoon hours were thus but 2.3 per cent. of those for the Kankakee; in other words, over 97 per cent. of the oxygen normal to these waters had been removed from them at this time by decomposition processes due to the amount of their organic contents.

The Bottom Sludges.—The silt and other deposits accumulating on the bottom of a stream are in some respects more significant of its average condition than are the waters of its current, especially so as many of our fishes obtain the greater part of their food from the bottom, upon which most of the plants and animals necessary to their support live continuously. The current opposite Morris is so rapid that the bottom is practically clean of sludge except where eddies and slack-water places are especially favorable to sedimentation. An extensive bar of sludge from three to eight feet deep has been formed in such a place between the wagon bridge and Kindlespire's landing, along the north shore of the Illinois. The upper two or three feet of this deposit, except for a thin upper stratum of grayish color, is a soft black ooze of homogeneous composition and a strong offensive odor. It contained, from September on, immense numbers of tubificid worms, in which respect it differed from the canal deposits at Lockport, which reached at the controlling works a depth, in places, of three or four feet. Plates of this sanitary-canal sludge spread out in thin layers and kept for thirty-six hours showed to the naked eye no signs of life.

An extensive deposit of sludge, five or six feet deep in places, has formed at the lower end of a large island half a mile above the Marseilles dam, and sediments a foot or more in depth have accumulated also in the chutes on each side of this island. In the north

chute, the main channel of the stream, the sediment was fine, heavy, black, and but little offensive, and contained few tubificid worms, the lighter organic matter evidently being carried down by the current; but in the more sluggish water of the south chute it was light, soft, and grayish, and full of *Tubificidæ*. For the first half mile above the dam the river bottom is mostly rock, covered by a thin layer of very soft ooze; but below the dam the swift flow of the stream keeps the bottom bare.

The chemical condition of the bottom deposits at this time is shown by the following table of the results of analyses of gases collected from the bottom sediments of the Illinois, at Morris, in August, 1911.

	Carbon dioxide	Oxygen	Carbon monoxide	Methane	Nitrogen
1	19.45	0.0	0.69	79.30	0.56
2	19.31	0.0	0.32	79.51	0.86
3	18.12	0.09	0.68	78.97	2.14
Means	18.96	.03	.56	79.26	1.19

This table is made more significant if it is brought into comparison with the following data of analyses obtained from the gases of the septic tanks of two sewer systems of Illinois towns.

	Carbon dioxide	Oxygen	Carbon monoxide	Methane	Nitrogen
Collinsville	17.98	0.23	0.34	81.26	0.0
Naperville	19.06	0.0	0.10	74.50	6.34
Means	18.53	0.11	.22	77.88	3.17

It will be seen that all of these samples are alike characterized by the virtual absence of oxygen, by the large percentages of carbon dioxide, and by the predominance of marsh gas or methane (CH_4), and that the Illinois River gases are indistinguishable from those of the tank sludges of the town sewers. The abundance of carbon dioxide and the absence of oxygen are, of course, to be understood as due to organic decomposition in the presence of oxygen; and the methane is evidence of the continuance of decomposition after the available oxygen was exhausted.

Collections of the bottom gases were made again at Morris September 5; and with a view to learning how far down the stream the bottom conditions found at this point were continued, like collections were made at Henry September 6, and above the dams at Marseilles. The chemical results are as follows.

	Carbon dioxide	Oxygen	Carbon monoxide	Methane	Nitrogen]
Morris	22.67	0.0	0.25	74.48	0.0
Marseilles	17.79	0.02	0.27	81.91	0.0
Henry	14.87	0.22	0.47	71.37	13.06

Sludge Worms.—It is clear that neither plants nor animals requiring oxygen could live in these sediments at the bottom of the stream. The abundance of *Tubificidæ* (*Limnodrilus* and *Tubifex*) imbedded in this sludge is explained by the extraordinary respiratory capacity of these worms, and by the fact that their respiratory structures are situated at the anal end of the body, which projects above the bottom and is kept continually waving back and forth. Their circulatory system likewise specially adapts them to life in water with a minimum amount of oxygen, the blood containing sufficient hemoglobin in solution to give it a red color, and being kept in active circulation through a closed system of blood-vessels.

Composition of the Sludges.—The following is a table showing the general composition of the sludges themselves according to analyses kindly obtained for us by the division engineer of the Sanitary District of Chicago, Mr. Langdon Pearse, the samples for which were furnished by ourselves at his request.

1911	Source	Specific gravity	Per cent. moisture	Per cent. in terms of dry matter			
				Nitrogen	Volatile matter	Fixed matter	Ether soluble
Sept. 5	Morris	1.21	69.2	0.64	14.8	85.2	1.18
Sept. 6	Marseilles	1.16	73.7	0.72	16.8	83.2	1.38
Sept. 6	Henry (above dam)	1.27	61.5	0.48	10.1	89.9	0.40

The greater specific gravity, the diminished moisture, and the smaller percentages of nitrogen and of fats in the sediments above the Henry dam, all indicate less organic matter in proportion to the

inorganic materials of the silt. As there is no reason to suppose that the river was carrying a larger load of mineral substances at Henry than at Marseilles, the differences of the table are probably due in part to a settling out, and in part to a decomposition of organic contaminations before the river water reached the Henry dam.*

Marginal Conditions, July, 1911.—The septic conditions above described were general at Morris for the stream as a whole, but were considerably modified along the margin in very shallow water, especially in pockets protected against the current. Water an inch deep near the north bank contained 3.5 parts per million of oxygen in the forenoon of August 31 and 6.1 parts in the afternoon, (38.9 per cent. and 69 per cent. of saturation,) while midstream samples gave 1.05 and 1.18 parts per million at the same hours (11.4 per cent. and 13.3 per cent. of saturation). The green-thread alga, *Stigeoclonium tenue,* formed many patches on the bottom even in July, in water four to six inches deep; and the oxygenation of the marginal water was largely the work of these plants. Here also were very many tubificid and naiid worms (*Tubifex* and *Dero furcata*), together with aquatic insects (*Notonecta, Nepa,* and *Gyrinidæ,* and a few *Chironomus* larvæ); but there were no clams (*Unionidæ*) or snails or crawfishes or larvæ of May-flies or of dragon-flies.

Plants and Animals of the Stream in general, July, 1911.—Generally speaking, the plants and animals of this part of the river in July, 1911, were either conspicuous by their absence, if clean-water forms, or by their excessive abundance, if pollutional or contaminate species. *Sphærotilus natans,* for example, was hanging to every stick or grass-blade along the edge, and to every suspended particle, small or large, and was attached everywhere to the stems of branching *Vorticellidæ*, especially to *Carchesium lachmanni.* Specks or larger collections of these two latter most abundant foul-water forms were so numerous, indeed, as to give the water a grayish look. There was every indication that these characteristic sewage organisms were coming at this time mainly from the Des Plaines above the mouth of the canal, and not directly from the sanitary canal itself, in which, in fact, they were not then abundant. The microscopic population of the large, soft masses floating down stream at Morris in July was mainly made up of a great variety of fungi, algæ, *Protozoa,* and rotifers, of which the most abundant were *Sphærotilus natans, Oscillatoria limosa, Colpidium colpoda, Carchesium lachmanni,* and *Rotifer actinurus.*

No fishes were seen or heard of here in the Illinois during this

*For additional data concerning the sludges in the winter time, and for all sections of the river, see p. 552.

month, although they were abundant in Mazon Creek, and in the slough at its mouth, which opens into the Illinois at Morris. Carp were noticeably numerous in this slough, and could be seen any sunny morning lined up along the edge of the river current, occasionally venturing into it a short distance, but quickly returning. After August 10, when rains brought the river up about six inches, the carp began to come out of the slough into the river along the south bank.

Late Summer and Autumn Conditions, 1911.—Towards the end of July, cooler weather and higher water produced changes which presently had their effect on the life of the river. The midstream temperature was 6.7° F. cooler on the 28th of July than it had been on the 22d, and a heavy rain August 10—the first excepting one light shower since our operations began, July 15—brought the river up about six inches. The fall rains began about the middle of September, and the river rose until, by October 5, it was four to five feet above the mid-July level. It then fell slowly about three feet in October, was brought up again a foot by November 11, and by the end of that month had declined to two and a half feet above the July stage. Water temperatures in the midstream ranged from 63° to 72° F. in August and September, and by November 3 (at 9 a. m.) were down to 41°. The midstream oxygen ratios of this late summer and autumn season averaged 1.44 parts per million in August, and stood November 3 at 4.55, or 16.5 per cent. of saturation for August and 41.3 per cent. at the beginning of November.

Reappearance of Fishes and other Animals.—By October, fishes had begun to appear to some extent in the river, even along the northern or contaminate side, where a few young perch, shiners (*Notropis atherinoides*), straw-colored minnows (*N. blennius*), and a single top-minnow (*Fundulus notatus*), were taken in places protected from the strong current. Shiners and straw-colored minnows were seen again in the same situations November 3, and carp were occasionally noticed on the south side of the river during the latter part of October. December 2, the first systematic attempt to take fishes at Morris was made, by hauling repeatedly a hundred-and-twenty-foot minnow seine in slack water along the north bank. Although weeds and sticks were slimy with *Sphærotilus natans* and *Carchesium lachmanni,* which were also floating in the shallows, numbers of young perch three to six inches long were captured here, together with many shiners—two to four inches—and a single black bullhead (*Ameiurus melas*), three inches long. An examination of the stomachs of these specimens showed that none of them had

recently taken food; but no other evidence of any abnormal condition was found.

Other and smaller animals, not detected in July, also made their appearance here as the season advanced. Water snails (*Planorbis* and *Lymnæa*) were seen on the south side of the river in August, and specimens were repeatedly taken on the north side from the first of September on. October 28 a large crawfish was noticed, apparently distressed however, and trying to leave the water. Large numbers of *Entomostraca* (*Cyclops prasinus*) were taken in the stream October 13, although only a few dead nauplii had been collected previous to that time. Female *Cyclops* bearing eggs were noticed in shallow water in protected pockets along the north shore after the September rise had scoured the river out. From November 1 to 8, healthy *Entomostraca,* largely a species of *Diaptomus,* were taken in considerable numbers both here and in the sanitary canal at Lockport, and free living nauplii were common in the collections from the sanitary canal.

Winter Conditions, 1912.—Winter conditions in February and March of 1912, when the river at Morris was partly frozen, were naturally in notable contrast to those of the midsummer season. The river level was unusually low for the winter, ranging from six inches to a foot above that of the preceding August. The water temperatures were, of course, near freezing. The mean of nine observations made February 16 was 33.8° F., and that of two observations made March 19 was 34.7°. There was doubtless no less organic matter in the water than before, and the sludge from the bar on the north side had now a strong privy odor, as of undecayed human feces, in place of the merely rank smell of the warmer weather. The water itself had a sloppy odor, and was apparently carrying more *Carchesium lachmanni* than in midsummer. Decomposition being, however, much slower at the winter temperatures, the oxygen content of the water was relatively high, ranging, February 16, from 6.3 to 7.2 parts per million, equivalent to an average saturation percentage of 48.76 for midstream samples.

The Winter Search for Fishes.—Persistent efforts were made at this time, under unusual difficulties, to learn whether fishes were to be found at Morris under these winter conditions. The use of minnow-seines, river-seines, and fyke-nets, was supplemented by repeated explosions of half-pound sticks of dynamite in different parts of the river. To haul the seines it was necessary to cut out the shore ice to a depth of one or two feet in order that the nets might be landed. In this way a dozen hauls were made with a 150-foot

seine of one-inch mesh. The nets fished well, as a rule, as far as seventy-five feet from shore, in the full current with water four to nine feet deep, but no living fish were taken by any of these hauls. Two dead shiners were in the net February 18, and a small specimen of the same species, in a dying condition, was picked up by hand near the shore February 24. It had perhaps been washed in from Au Sable Creek. A hoop-net, with a 6-foot opening, and two smaller fykes with 2-foot and 3-foot openings were kept continuously fishing from February 20 to March 2, alternating between the north and the south shores, but not a fish was taken by them at any time. Twenty-four sticks of dynamite were exploded on both sides of the river and in the midstream, but the only fish to appear was a single shiner, near the south shore, a hundred yards above the mouth of Mazon slough. February 28, a neighboring farmer found a 15-pound carp on the ice near the north shore below Au Sable Creek. The fish was probably sick or suffocated, and trying to get air. On the 2d of March, several perch and shiners, and a single carp eight or ten inches long, were taken in cleaning out the pump-house tank of the Rock Island Railroad, the intake of which is seventy-five feet from the north shore of the stream. As the tank had last been cleaned February 1, these fish must have been pumped in since that date. The stomachs and intestines of all the specimens taken at Morris between February 16 and March 2 were quite empty.

Summer and Fall of 1912.—In August and September, 1912, Morris was twice visited for systematic collections of fish and of the shore and bottom forms of animals and plants—the first time August 1 to 10, and the second, September 23 to October 1. The river level stood, in the beginning, at twenty inches above the July stage of 1911, fell slowly to eight inches above by September 22, and then rose to eleven inches by the end of the month. Specks of suspended matter, largely *Sphærotilus* and *Carchesium*, gave the water a grayish hue, and its smell was the same as in the summer of 1911, but less offensive. There was also less bubbling of gases from the bottom, but the odor of the sludge was not noticeably different.

Chemical determinations were made during this period only on the 27th of September, at which time, with a water temperature of 62.7° F., the oxygen reading for both the north shore and the main stream was 17.9 per cent. of saturation (1.8 parts per million), and that for the south side was 37.4 per cent. (3.7 parts per million).

Persistent fishing was done with dip-nets, seines of various sizes, set-nets, trammel-net, dynamite, dredges, and the mussel-bar,—the last for Unios. Seven fishes were taken at this point in all—five of

them black bullheads (*Ameiurus melas*), one a rock bass (*Ambloplites rupestris*), and one a blue-gill sunfish (*Lepomis pallidus*). These were all taken in set-nets in the less polluted water of the southern or Kankakee side of the river—the bullheads near the outlet of Mazon slough, and the rock bass and sunfish about seventy-five yards above. They were the entire product of a haul of the 200-yard seine, made on the north shore August 2; five settings of the trammel-net on the south side of the river; continuous fishing with three and four set-nets August 2 to 9; fifteen hauls with small seines made on both shores, September 25; and the explosion of twenty half-pound sticks of dynamite, August 2 to 9, near both shores and in the middle of the stream. The river here was, in fact, practically destitute of fishes, and the few taken were in close proximity to the Mazon slough. Moreover, some of the bullheads were "fungused" or in otherwise unwholesome condition.

The only other vertebrates taken here were a single frog, two snapping turtles, and a soft-shelled turtle. The search for mollusks yielded seven species of mussels, all the specimens dead, however, except for one collection made in Mazon slough. Snails were obtained several times—*Campeloma, Goniobasis,* and *Pleurocera* all dead, but *Planorbis, Physa,* and *Lymnæa* alive in part, six collections containing living specimens of these genera and nine collections containing dead. No *Sphærium* or *Pisidium* were taken here, nor any *Bryozoa,* sponges, or hydroids.

Numerous samples of sludge from the bottom were spread in thin layers on plates, and left for the animals to emerge, with the result that tubificid worms appeared in numbers varying from 12 to 200 per plate. These were most abundant in samples taken nearest the shores. There were no leeches or planarians in our collections, but four of them contained naiid worms (*Dero furcata*). A single crawfish was taken in Mazon slough, and bleached, unwholesome-looking specimens of an amphipod crustacean (*Hyalella knickerbockeri*) were present in the duckweed along the south bank. Several species of water-beetles and water-bugs were found along both shores, but, with the exception of larvæ and pupæ of *Chironomus,* these were all adults which take their oxygen from the air and not from the water. There was some pondweed (*Pontederia*) and duckweed (*Lemna* and *Wolffia*) along the banks.

No later collections were made at Morris in 1912, but we have additional oxygen determinations for November 2 and November 14. The following table gives these data for the midstream and the two shores on these two dates.

	Date	Temperature F.	Oxygen	
			Parts per million	Per cent. saturation
North shore	Nov. 2	48.2	4.8	41.4
North shore	Nov. 14	46.4	6.5	54.6
Midstream	Nov. 14	46.4	6.8	57.2
South shore	Nov. 14	46.8	8.7	73.1
South shore	Nov. 2	48.2	6.5	56.

Illinois River at the Marseilles Dam

Above the Dam.—In midsummer, 1911, the water at the Marseilles dam had a grayish look and a disagreeable odor, but with perceptibly less material in suspension than at Morris. There was no bubbling of gases from a bar of sludge at the point of the island half a mile above the dam, but chunks of sludge were floating to the surface on the warmest days. The odor of this bottom sediment was the same as at Morris and from the sanitary canal at Lockport. The surface temperature was 71° F. July 30, 72° August 11, and 71.9° August 24.

The situation a quarter of a mile above the dam may best be described by a comparison with that at Morris, these points being but seventeen miles apart, with no important tributary of the river or other modifying factor coming in to interfere with the spontaneous development of conditions within the stream itself. Another important and interesting comparison is that of chemical and biological data from above and from below this dam, since this comparison will show us what and how great are the effects of the fall upon a polluted water.

We may notice first that the mixture of Kankakee and Des Plaines water was evidently complete above the dam at ordinary stages, the two shores and the middle of the stream differing but little in respect to their ratios of oxygen and carbon dioxide, and not always in the same direction as at Morris. The north, or Des Plaines, shore water at Marseilles was, indeed, somewhat more oxygenated than that of the south, or Kankakee, shore water, both in February and in August, 1912—the only months when tests available for this comparison were made. More precisely, the north side oxygen ratios were 3 per cent. higher than those on the south side February 20 to 22, and 11 per cent. higher August 21; while the midstream percentages were a little lower than those of either shore in February, and a little higher than either in August. Such differences may be regarded as either

negligible in amount or due to local conditions. In November, 1911, however, after a flooding rain which brought the river up some three feet, midstream water above the dam contained thirty per cent. more oxygen than north-shore water below the dam—a relation the reverse of that found at this point at any other time. This can only be understood as due to the fact, already commented upon under Morris, that, at this stage of the river, Des Plaines and Kankakee waters were still imperfectly mixed even at Marseilles. The midstream samples, taken nearer the south shore than the north, were evidently Kankakee water, and the north-shore water, on the other hand, was still essentially that of the Des Plaines.

In July and August, 1911, when the midstream microplankton of the river was collected at several stations between Dresden Heights and Chillicothe, specimens of septic species were nearly all *Sphærotilus natans*. In the first collections, made during the last days of July, this species was the most abundant at Dresden Heights, considerably less so at Morris, and almost insignificant in number at Marseilles, the actual figures of individual specimens per cubic centimeter of water for those three points being 186, 117, and 9 respectively. Counts of *Carchesium* and *Epistylis*, also saprobic species, were likewise much below those at Morris. A like difference in the yields of septic species between Morris and Marseilles was found in the collections of August 11 and 12 and August 23 and 24, when the average numbers per cubic centimeter were 62 and 12 for these two points respectively. This reduction in numbers down stream is probably to be understood, however, as mainly due to a mere settling out of particles carrying these organisms, and not to a change in the character of the water.

We have no exactly comparable chemical data for July; but analyses for August show oxygen ratios of 20.4 parts per million at Morris on the 11th and 11 parts at Marseilles on the 12th, and of 16.35 parts per million at Morris on the 22d and 23d and 7.4 parts per million at Marseilles on the 24th and 25th. The carbon dioxide ratios, on the other hand, were much larger at Marseilles than at Morris on these dates. Active decomposition of organic matter was thus clearly evident in this midsummer weather, at the low stage of water then prevailing. With higher water and cooler weather the differences between Morris and Marseilles were greatly diminished, the percentages of saturation February 16 to 20 standing at 48.76 for Morris and at 43.70 for Marseilles. In the fall of the following year these ratios were, in fact, reversed, the Marseilles determinations being 5 per cent. higher than at Morris September 27 and 9 per cent. higher November 14.

Alongshore July and August collections, in 1911, were similar to those at Morris, consisting mainly of *Sphærotilus natans,* rather less abundant than above, and *Stigeoclonium tenue,* found only in shallow protected places. Here also were back-swimmers (*Notonectidæ*), a few *Chironomus* larvæ, and miscellaneous oligochæte worms. A few crawfishes were captured inside or near the mouths of creeks. No Unios were seen here, either dead or alive; but a small bivalve mollusk (*Sphærium transversum*) was abundant in protected pockets along the north shore in water six inches to a foot deep, and a few living specimens of *Physa, Lymnæa,* and *Planorbis* were taken in similar situations. The bottom sludge contained at this time the same slime worms (*Tubificidæ*) as were found at Morris, as many as fifty per plate near the south shore in October, 1912.

In August and October, 1912, our more extensive collections gave us a larger list of species, of which only the most significant will be mentioned here. Besides the septic *Sphærotilus, Carchesium,* and *Epistylis,* which were less prominent than above, but still everywhere abundant, there were, at Marseilles the three blue-green algæ, *Lyngbya versicolor, Oscillatoria limosa,* and *Phormidium uncinatum,* the two latter of which are classed as pollutional and contaminate, respectively. The filamentous algæ most frequently obtained along shore were species of *Stigeoclonium, Cladophora, Spirogyra,* and *Ulothrix,* mentioned in the order of their abundance in our collections.

The organisms of the sludge, were, of course, the same as those of the preceding year. A marked difference was noticed between the chutes on the opposite sides of the island which divides the river a short distance above the falls. The current in the south chute is relatively weak, and the bottom sediments here were fine, light, and full of sludge worms; while in the strong current of the north chute the silt was denser and darker, with few or no *Tubifex.* Oligochæte worms, including naiid species, were found also in the ooze along shore, especially abundant among growths of the blue-green alga *Lyngbya.* Leeches were only occasional. There were no shore or bottom crustaceans seen at Marseilles except certain species of *Cyclops,* abundant among algæ and duckweed along the margin of the river, and a few crawfishes found only at or within the mouth of a small tributary creek. Our collections of adult insects made at this place represent fourteen genera, but the larvæ, except those of mosquitoes and horse-flies (*Tabanidæ*), found each in but one collection, were those of *Chironomus.* Both blood-red and yellow species with pupæ and unhatched eggs were obtained in twenty-one collections. No living Unios were secured either above or below the

dam, although the mussel-bar was diligently used in both places. A small bivalve mollusk, *Sphærium transversum,* was abundant along the north shore; and the univalves were much the same as at Morris. Living specimens of the following species were collected: *Lymnæa desidiosa, L. humilis, L. reflexa, L. palustris, Planorbis trivolvis, Succinea ovalis, Physa gyrina,* and *Polygyra multilineata*— the last alive in only one collection.

The yield of our fishing operations was somewhat more varied at Marseilles than at Morris, but only in the immediate neighborhood of small creeks and springs, where the water was locally or temporarily more tolerable than in the main stream. No trace of fishes was found above the Marseilles dam during July or August, 1911; and it was not until October 13 that a few minnows (*Cyprinidæ*), not identifiable at the distance, were seen near the north shore a quarter of a mile above the dam.

November 30 and December 1, 1911, hauls were made with a 120-foot minnow seine and a 150-foot one-inch mesh seine, on both the north and south shores, some three eighths of a mile above the dam; and in the vicinity of small creeks. Many young perch and shiners (*Notropis atherinoides*), a black bullhead, and a young carp were captured here at this time. None had taken food except two perch, one of which had eaten a small shiner and the other a naiid worm. February 20 to 29, 1912, two 6-foot set-nets, kept in place along the north shore, were lifted daily, a 120-foot minnow seine was hauled in water two to four feet deep, and 26 half-pound sticks of dynamite were exploded on both shores and in the mid-channel. No fish were taken in the set-nets; a single small shiner was caught with the minnow seine; and two perch and several shiners were got with dynamite. The stomachs of all were empty.

In August and September, 1912, conditions were similar to those found at Morris at the same time. Set-nets were raised every day from August 13 to 17, but without result; and a dozen half-pound sticks of dynamite were exploded, but no fish were taken. Small seines were used on the north and south shores, and the fishes thus caught, within or near the mouth of a small creek on the northern side, were as follows: black bullhead, 1; common sucker, 2; striped sucker (*Minytrema melanops*), 1 golden shiner (*Abramis chrysoleucas*), 1; bullhead minnow (*Cliola vigilax*), 12; straw-colored minnow (*Notropis blennius*), 1; young crappie, 1; rock bass, 6; pumpkinseed (*Eupomotis gibbosus*), 1; orange-spotted sunfish (*Lepomis humilis*), 1; and Johnny darter (*Boleosoma nigrum*), 4. On the night of August 19, a heavy rain, which flooded the small creeks,

washed fishes out into the river, where they became sick from sewage and could be picked up easily with a dip-net. The following morning a 3-pound carp, 2 horned dace (*Semotilus atromaculatus*), and an orange-spotted sunfish were obtained in this way. Several hauls with small seines were made October 4, but no fish were caught except a few bullhead minnows at the mouth of one of the creeks.

Below the Dam.—Turning now to the situation below the dam at Marseilles, we find that in July and August, 1911, the ratios of dissolved oxygen three fourths of a mile below were more than three times as great as those just above*; that under winter conditions in February and March they were 13 and 14 per cent. greater; and that in August and September, 1912, with cooler weather and higher river levels than in the previous year, they varied from one and a half to two times as great. The necessity of taking samples for analysis at some distance below the fall was shown by the fact that the oxygen content of the water September 1, 1911, an eighth of a mile below, was more than ten times that above—a discrepancy to be accounted for only on the supposition that the air mechanically caught in the water at the fall had not yet had time to escape. The water below the fall in 1911 was visibly cleaner than that above, and there was less *Sphærotilus natans* in the plankton collections. This was probably due in part to sedimentation in the slack water above the dam, and in part to the pulverization of the coarser organic particles by the pounding of the water at the fall.

We were told by observant residents, in 1911, that fishes usually come up to Marseilles in some variety—bass only in the highest water, but carp in both summer and winter of every year; but none of either were seen or heard of there in July and August of that year. Strings of black bullheads were being caught below the dam October 13, 1911, and carp were said to have been common there since the fall rains began. Our winter fishing with set-nets and dynamite was, however, no more productive than at Morris. Small nets set in February, 1912, from one hundred to two hundred yards below the dam, near the north shore, caught only two shiners, and were then destroyed by floating ice; and six sticks of dynamite, exploded from a half to three quarters of a mile below the dam, gave us only two more of the same species. The stomachs of all these fishes were empty.

August 14 and 15, 1912, we found essentially the same conditions as to fishes below the dam which were found above, except that we

*It was impossible to reach the center of the stream here, and samples were taken from the stern of a skiff fifteen feet from the north shore, in water two feet deep. The current at low water, July 31, was estimated at five miles per hour.

got a greater variety of species in shallow water along shore near the mouths of small tributaries. From the full current of the river only a dozen specimens of a shiner (*Notropis atherinoides*) were captured, and these by dynamite explosions, the set-nets coming up empty. By the use of small seines and dynamite we obtained in shallow water along shore examples of the species shown by the following list.

FISH COLLECTIONS, BELOW THE DAM, MARSEILLES, AUGUST 14 AND 15, 1912

	River; full current. Dynamite	River, near mouth of small creek. Dynamite	River, near mouth of spring rivulet. Seine	Small creek, within mouth. Seine	Totals
Common sucker		2	6	7	15
European carp		2	1	2	5
Red-bellied dace (*Chrosomus erythrogaster*)			1	1	2
Blunt-nosed minnow (*Pimephales notatus*)			2	1	3
Horned dace			6	1	7
Golden shiner		1			1
Straw-colored minnow (*Notropis blennius*)			1	1	2
Notropis gilberti			1		1
Silverfin (*Notropis whipplii*)		1			1
Shiner (*Notropis atherinoides*)	12				12
Sucker-mouthed minnow (*Phenacobius mirabilis*)			1	1	2
Black-nosed dace (*Rhinichthys atronasus*)			14	15	29
Black bullhead		2			2
Pumpkinseed		1			1
Rainbow darter (*Etheostoma cœruleum*)				1	1
Totals	12	9	33	30	84

A comparison of the fourth column with the others preceding makes it probable that most of the specimens taken from the river here were migrants from the creeks, and if not it is certain that the creek waters along shore were being commonly sought by them. A notable exception is the abundant shiner (*N. atherinoides*), which we shall find the commonest fish in our river collections all the way to Chillicothe.

The microplankton was, as might be expected, virtually the same as above, except that the number of organisms per cubic centimeter was only about four fifths as great below, possibly because many of

the more delicate of the *Protozoa* were killed by the pounding of the falling water. Univalve mollusks were not only living, but were breeding here August 25; whirligig beetles—mostly *Gyrinus analis*—were common; large isopod crustaceans—*Asellus*—were taken here for the first time; and a few slime worms (*Tubifex*) were found where soft mud was deposited in sheltered places, the current being too swift for any considerable accumulation of bottom sediments.

In respect to organisms of other classes, the differences above and below the dam were merely trivial, unless we may attach some importance to the fact that our first specimens of the bryozoan *Plumatella repens*, were taken below. This species was not found above Marseilles, but occurred regularly at the various stations from that point downward.

Ottawa

No collections were made at Ottawa in 1911; and the several oxygen determinations of September 2 of that year are of little use for comparison, since the samples were all taken near the south shore above the mouth of the Fox River, from only six inches below the surface, in water but two feet deep. They averaged 5.34 parts per million, or 63.1 per cent. of saturation. The carbon dioxide on this date varied from 4.2 to 5.5 parts per million, with an average of 4.66.

August 22, 1912, oxygen tests from each side of the river above the Fox, averaged 3.65 parts per million. November 2 the water of the Illinois above the Fox gave 5.7 parts per million; and that of the Fox itself nearly twice as much (11.2 parts per million).

In 1912, biological collections were made here for seven days, August 22 to 28 inclusive. Dip-nets, small seines, dredges, the mussel-bar, and dynamite, were variously used, according to the situation and the object in view. The water at this time had a distinct sewage odor, somewhat less noticeable, however, than at Marseilles, and among the weeds along the banks was an oily, tar-like scum similar to what had been noticed in the sanitary canal at Lockport. It apparently originated in gas-house wastes. Other more or less recognizable objects from the sewage were more abundant here along shore than usual, possibly because a heavy rain which had fallen three days before, bringing the river up about a foot, had flushed out the Des Plaines.

The river sludge obtained at various points did not differ appreciably from that above, either in sensible character or in organisms contained, except for the occurrence of a few living snails and speci-

mens of the bivalve mollusk *Sphærium*, found in a somewhat sandy deposit two hundred yards below the Ottawa wagon-bridge. The characteristic foul-water organisms, *Sphærotilus, Carchesium*, etc., although common in weeds along the edges of the stream, and obtained also from the current, were less abundant than at Marseilles. The same blue-green and filamentous green algæ found at Marseilles were collected here also. There were no sponges, hydroids, or planarians; but leeches occurred now in fourteen collections. *Cyclops* was found among the marginal algæ, as above, and a single isopod crustacean, *Asellus*, was taken in the drift on the south shore.

The lessening of contaminate conditions was especially shown by the occurrence of small numbers of various insect larvæ, including those of dragon-flies, caddis-flies, and May-flies (*Cœnis* and *Hexagenia*), and pupæ of the sand-fly (*Simulium*). Larvæ and pupæ of *Chironomus* were obtained in twenty-two collections. Diligent use of the crow-foot dredge in various situations brought to light no living mussels except on a bar in Fox River water just outside the mouth of that stream. Here two species were obtained alive—*Lampsilis ventricosa* and *L. lævissima*—and dead shells of eight other species. One large specimen of *Anodonta corpulenta* had quite recently succumbed, the flesh being not yet decayed.

Species of univalve mollusks, taken largely by the Ekmann dredge from the bottom of the main stream, became at this point rather too numerous for special mention in a preliminary report. *Planorbis trivolvis* and *Physa gyrina* were the most abundant, and a species of *Amnicola* next. The number of dead shells of both Unios and univalves, as compared with the living specimens found, was indicative of an environment still difficult for mollusks.

Our fish collections at Ottawa were made August 26 and 27, 1912, with small seines and dynamite. They aggregated one hundred and twenty-five specimens, representing seventeen species, of which forty-six specimens belonging to fourteen species were from Fox River water just outside the mouth of that stream. From the water of the Illinois itself, we have the following six species: 1 carp, 1 black bullhead, 1 red-horse, 2 blunt-nosed minnows, 2 horned dace, and 69 shiners, 18 more of the last coming from the Fox River water. The seines gave us fifty-eight specimens of fifteen species; and the dynamite explosions, sixty-seven specimens of six species. Only two of the latter, the carp and the horned dace, were secured by dynamite which did not also come out in the seines. The following is the complete list.

FISH COLLECTIONS AT OTTAWA, AUGUST 26 AND 27, 1912

	Illinois River, near mouth of Fox. Seines	North shore, above Fox. Seines	North shore, between bridges. Seines	Half mile below C. B. & Q. bridge. Dynamite	South shore, above Fox. Dynamite	South shore, one mile below C. B. & Q. bridge. Dynamite	South shore, near lower end of city. Dynamite	Totals
Gizzard-shad *Dorosoma cepedianum*	1	1		1				3
Quillback *Carpiodes velifer*	6							6
Chub-sucker *Erimyzon sucetta oblongus*	1							1
Common red-horse *Moxostoma aureolum*	2			1				3
European carp				1				1
Blunt-nosed minnow *Pimephales notatus*	4			1	2			7
Horned dace *Semotilus atromaculatus*					2			2
Bullhead minnow *Cliola vigilax*	1							1
Straw-colored minnow *Notropis blennius*	3							3
Silverfin *Notropis whipplii*	2							2
Shiner *Notropis atherinoides*	18		10	29	23	2	5	87
Black bullhead *Ameiurus melas*		1						1
Orange-spotted sunfish *Lepomis humilis*	1							1
Bluegill *Lepomis pallidus*	1							1
Pumpkinseed *Eupomotis gibbosus*	3							3
Small-mouthed black bass *Micropterus dolomieu*	2							2
Large-mouthed black bass *Micropterus salmoides*	1							1
Totals	46	2	10	33	27	2	5	125

From a comparison of the first column of this table, showing the collections taken from the shallow water near the mouth of the Fox, with the other columns, it is plain that Fox River water was greatly preferred by fishes at this place, and it seems likely indeed, that most of the specimens taken at this point had come into the river from the Fox itself. The common shiner is, as usual, a notable exception, this abundant lake and river minnow being unusually tolerant of polluted waters.

Starved Rock

The odor of the water at Starved Rock, August, 1911, was still disagreeable, but there were no bubbles of gas from the bottom, and there was sensibly less suspended matter in the water than at Marseilles. North of the island the stream was perceptibly cleaner and of a greener color than in the south channel, probably because it carried a larger admixture of Fox River water, with its greener plankton. The surface temperature of the water was 78° F. August 15, and 72° August 26. The effect of Fox River contributions to the Illinois was plainly manifest by an average difference of 21 per cent. between the oxygen ratios of the two sides of the Illinois, as shown by seventeen sets of tests made August 15 and 26, 1911, and February 23, August 22, September 6 and 28, and October 11 and 26, 1912. The lowest ratio of the series was 2.5 parts per million from the south shore, September 6, 1912, and the highest was 5 parts per million, also from the south shore, October 26. The general average for the south shore was 3.23 parts per millon (35.9 per cent. of saturation), and that for the north shore, with its larger admixture of Fox River water, was 3.91 parts per million (43.6 per cent. of saturation).

The only sewage organisms found were isolated filaments or minute tufts of *Sphœrotilus natans* floating in the current. Minnows, identified as golden shiners and spot-tailed minnows (*Notropis hudsonius*) were seen swimming near the surface on both sides of the river. This is the first observation of the second of these species. An old resident of the town informed us that a considerable variety of fishes is to be found here, practically at all times, but that the numbers are never large.

In 1912, collections were made at Starved Rock September 3 and 9 and October 9 to 11. The water had still a slight sewage odor, but less than at Ottawa. *Sphœrotilus* and *Carchesium* were occasionally seen attached to weeds and grass at the edge, and moderate

numbers of small particles composed of them were floating down stream. Samples of sludge obtained at this time were full of slime worms, as usual, those from the chute on the north side of the island averaging a hundred per plate, and those from the south side twice as many. In the north chute were also many living snails, especially *Campeloma* (which was very abundant) and a much smaller number of *Physa* and *Pleurocera*. The sludge collections from the south shore contained some *Campeloma*, but none of the other snails. In the channel below the island the current was too swift to permit the deposit of a fine sediment, and the bottom was sandy, with dead snails only. The only blue-green algæ were a *Lyngbya* and a *Phormidium*, taken in three collections, while filamentous green algæ occurred in thirty-seven. The most abundant forms were *Cladophora*, both *crispata* and *glomerata*, and *Stigeoclonium tenue* and *lubricum*. Living sponges were obtained on dead mussel shells in three collections.

The isopod *Asellus* was common in dredge hauls and among the algæ at the edge. Crawfishes were taken here in two collections, and *Chironomus* larvæ and pupæ in seventeen. The situation was not productive of Unios, and but two species were taken alive—*Quadrula plicata* and *Symphynota complanata*. Five collections contained both dead and living *Sphærium transversum*, and four contained living *Ancylus*. Statoblasts of *Plumatella* were abundant in the drift, and other *Bryozoa* were common on shells of dead and living mussels.

Our fishing at this point was mainly done September 3, between Starved Rock and the mouth of the Vermilion. A quarter of a mile below the landing, on the north shore, at the mouth of a creek, a dynamite explosion gave us a blunt-nosed minnow, many shiners, a *Notropis jejunus*, a large-mouthed black bass, and a gizzard-shad. A half-mile below, dynamite and a 60-foot seine yielded a very large number of shiners, three silverfins, a golden shiner, and a short-headed red-horse (*Moxostoma breviceps*). A haul of the 60-foot seine on "Little Rock bar" near the south shore brought in several hundred young carp from two to five inches long, a great abundance of shiners, and a black bullhead. A haul in the channel with a 200-yard seine with an inch mesh, on the other hand, brought in no fish. A dynamite explosion near the south shore, three quarters of a mile above the mouth of the Vermilion, brought to the surface three 2-pound carp and many shiners. Additional dynamite explosions made September 3 and 4 at five different points down the river as far as Spring Valley, gave us large numbers of the shiner (*Notropis atherinoides*), but no other specimens except a 3-inch carp and four golden shiners.

From the following complete list, compared with that made at Ottawa, it seems that the fishes taken here represented the normal river stock at this place, with practically no immediate admixture from small tributary streams.

1 Gizzard-shad (*Dorosoma cepedianum*).
3 Carp, adults, and several hundred young.
1 Short-headed red-horse (*Moxostoma breviceps*).
1 Blunt-nosed minnow (*Pimephales notatus*).
5 Golden shiner (*Abramis chrysoleucas*).
3 Silverfin (*Notropis whipplii*).
1 *Notropis jejunus.*
Very many shiners (*Notropis atherinoides*).
1 Black bullhead (*Ameiurus melas*).
1 Large-mouthed black bass (*Micropterus salmoides*).

La Salle-Peru

In August, 1911, the water at Peru had still a grayish look, was full of very minute grayish particles, and had a slight sewage odor, more pronounced near the northern side, partly, no doubt, because of sewage entering the stream at La Salle and Peru. The presence of Vermilion River water on the south side probably increased this difference. The water temperature August 2, was 72° F. The only collections made, besides those of fishes reported above, were mussels obtained in 1912 by the use of the mussel-bar. Thirty-six specimens, representing ten species, included twelve living specimens of five of the species only, namely, *Lampsilis alata, L. ligamentina, L. gracilis, Quadrula plicata,* and *Symphynota complanata.* The large proportion of dead specimens, as compared with the ratios obtained farther down the stream, indicate unfavorable conditions for mussels in the stretch of river between Utica and Peru. The following is a complete species list.

Species	Alive	Dead
Lampsilis alata	1	4
L. gracilis	1	1
L. ligamentina	4	3
L. ventricosa		4
Obliquaria reflexa		1
Quadrula ebena		1
Q. plicata	5	3
Q. pustulosa		1
Quadrula sp.		3
Strophitus edentulus		1
Symphynota complanata	1	2
Totals	12	24

The only chemical tests at this place were made August 2, 1911, and July 11 and November 15, 1912. August 2, the oxygen ratios opposite Peru varied from 3.17 to 3.51 parts per million (35.8 to 39.6 percentages of saturation), according to the place in the river from which the samples were taken. A carbon dioxide test of water taken from near the south side of the stream under the bridge gave 6.6 parts per million.

July 11, 1912, the oxygen in the river at Peru was lower than in the preceding August—2.7 parts per million, equivalent to 32.2 per cent. of saturation at the temperature of the time. November 15, on the other hand, the oxygen ratio was 8.9 parts per million—71.3 per cent. of saturation. As the old Illinois-Michigan Canal opens into the Illinois River at La Salle, it was a point of interest to know the character of the water which it was adding to the stream at that place. July 11, 1912, the oxygen ratio within the mouth of the canal was 4.31, and November 15 it was 9.7—the former 51 and the latter 75 per cent. of saturation. Local contaminations by sewage, gas wastes, and wastes of the zinc works were disturbing elements at La Salle, the situation being further complicated by the inflow of uncontaminated water through the Vermilion, a short distance above on the opposite side of the Illinois, and the station was consequently dropped in 1912.

Spring Valley

July 11, 1912, there was decidedly less oxygen in the water at Spring Valley than at Peru—1.95 parts per million, as compared with 2.7 parts, the water temperatures being 77° F. at both points.

November 15, however, the oxygen ratios were precisely the same—8.9 for each. The loss of oxygen down stream in July was perhaps due to a rapid hot-weather decomposition of sewage materials received at Peru and La Salle.

Our only collections at Spring Valley were made with dip-nets, dredges, and small seines October 15 to 18, 1912. The water, even this far down the stream, had a noticeable sewage odor and a grayish color, with no tinge of green; but it improved greatly before reaching Hennepin, where it was odorless and of a greenish hue. The bottom sludge changes more slowly, however, as one goes down stream, and samples taken October 18 a quarter of a mile below Spring Valley in water twelve feet deep were still swarming with *Tubifex*—several hundred to the plate. At Spring Valley the weeds and grass at the edge of the river were free from *Sphærotilus* and *Carchesium,* and these sewage organisms were not taken in the plankton. No blue-green algæ were found here except a small quantity of *Lyngbya versicolor;* and the green filamentous algæ were mainly *Cladophora crispata* and *Stigeoclonium tenue,* with some *Ulothrix, Oscillaria,* and *Vaucheria.* Sponges were found on the mussel shells; leeches occurred in eight of the collections; *Cyclops* was abundant in the algæ; and shells of five species of mussels were dredged from the bottom—all dead, however, except one specimen of *Quadrula pustulosa.* Among the other living mollusks were many *Campeloma, Planorbis trivolvis, Sphærium transversum, Pisidium,* and *Ancylus;* and a few other species were represented by dead shells. *Plumatella repens* was common on logs.

Depue

Similar collections were made October 17 and 18, 1912, from the Illinois River, opposite Depue Lake. The sludge at this point was less offensive than above, and contained but fifty specimens of *Tubifex* per plate. Three of the collections contained the isopod crustacean *Asellus. Ostracoda* were in the duckweed along shore, together with the crustacean *Hyalella knickerbockeri,* the first to occur in these river collections below Lockport. Here also was taken the first specimen of the common river shrimp, *Palæmonetes exilipes.* Caddis-fly larvæ were abundant on mussel shells, and dragon-fly nymphs were taken in five collections. Six species of mussels—*Quadrula heros, Q. plicata, Q. pustulosa, Q, asperrima, Anodonta grandis,* and *Tritogonia tuberculata*—were represented by living specimens taken in a small dredge. *Succinea, Campeloma, Planorbis,*

Sphærium, Pisidium, and *Ancyclus* were all abundant, as was also *Plumatella repens* on sticks and logs.

In Depue Lake itself dip-nets, dredges, and small seines yielded many common worms not found above, naiids, planarians, etc., and *Hyalella knickerbockeri* was abundant among algæ, in all situations. Insect larvæ were likewise present in unusual variety, including *Chironomus* and *Ceratopogon* larvæ, larvæ of caddis-flies and May-flies (*Cænis* and *Callibætis*), tipulid larvæ, and larvæ of several species of larger dragon-flies and damsel-flies (*Agrioninæ*). Among the mollusks were *Quadrula undulata, Q. plicata, Vivipara contectoides, Lioplax, Sphærium transversum,* and *Ancylus,* besides a number of species represented only by dead shells. Fishermen believe that the poisonous wastes from the Depue zinc works are killing the shells on the bottom of this lake. It was here that the first commercial fisheries were encountered; and a haul made at the foot of Depue Lake October 18, yielded about two hundred pounds of carp and a hundred pounds of sunfish and crappies.

Hennepin to Henry

At Hennepin the water became to all appearance practically normal, even in the midsummer of 1911, being odorless, greenish with phytoplankton, and free from suspended clusters of foul-water organisms and particles of sewage debris. Here we found commercial fishing in progress in both the river and the adjacent lakes, mainly, however, in the latter. Mud taken in September from the bottom of the channel at Hennepin was more sandy than above, had no offensive odor, contained many snails—*Campeloma, Pleurocera,* etc., many specimens of *Sphærium transversum,* and only a moderate number of slime worms. Similar materials were obtained from the bottom at the Henry dam, except that the sediments in the sluggish current there were softer, finer, and darker than in the full flow of the stream at Hennepin. At the low temperatures of March, 1913, however, the sludge was offensively corrupt much farther down the stream than in the warmer season, as will be more fully explained under the next section. The midsummer microplankton of 1911 confirmed the other lines of evidence, yielding but 2 septic organisms to the cubic centimeter as compared with 16 at Starved Rock and 80 at Morris; and 6 pollutional forms as compared with 7 at Chillicothe below, 71 at Starved Rock, 134 at Marseilles, and 142 at Morris. Forms classed as contaminate, on the other hand, were more numerous both here and at Chillicothe than above, and clean-

water forms were 138 to the cubic centimeter at Hennepin, 744 at Chillicothe, and 154 at Marseilles, as compared with 193 at Morris. Oxygen ratios were a little lower in July, August, and September than at Starved Rock, and somewhat higher in October and November.

As this was the first station at which the life of the river may be said to have found virtually normal conditions, some further testimony to that effect may be drawn from our collections of mussels and fishes. Seventeen species of mussels were collected alive, and five others were represented only by dead shells. Of these *Lampsilis fallaciosa, Quadrula plicata, Symphynota complanata, Anodonta corpulenta,* and *Quadrula heros* were the most abundant, in the order named, and, with a single exception, all the specimens of these species were alive. The number of living shells as compared with dead ones is in marked contrast to the conditions found above. The following is a complete list.

HENNEPIN, 1912

Species	Alive	Dead
Alasmodonta confragosa	1	1
Anodonta corpulenta	14	
A. grandis		1
A. imbecillis	1	
Anodontoides ferrussacianus	1	
Lampsilis alata	5	
L. fallaciosa	60	
L. gracilis	10	1
L. lævissima	2	
L. ligamentina	1	4
L. luteola	8	4
L. occidens		1
L. parva	1	
L. ventricosa		2
Quadrula asperrima	2	1
Q. heros	11	3
Q. plicata	45	
Q. pustulosa		2
Q. trigona	1	1
Q. undulata		1
Strophitus edentulus	1	
Symphynota complanata	23	1
Totals	187	23

The following fishes were taken September 6 and 13 from the river in the vicinity of Hennepin, by seven hauls of a 30-yard minnow seine, 15 hauls with a 200-yard seine with an inch mesh, and a single haul made for us by a fisherman with a common river-seine.

Hennepin, 1912

Short-nosed gar, 1
Dogfish, 3
Common sucker, 1.
European carp, 174.
Shiner, many.
Golden shiner, many.
Speckled bullhead (*Ameiurus nebulosus*), 1.
Black bullhead, 1.
Black crappie (*Pomoxis sparoides*), 1.
Warmouth (*Chænobryttus gulosus*), 1.
Blue-gill sunfish, 3.

The weather was very hot when the larger seines were used, ranging above 90° F. every day, with the water at 79°, and the fishing was unusually poor.

Henry to Chillicothe

As this is the final section of our series, a fairly full description of conditions found and collections made will be desirable for comparison. Even under the midsummer conditions of July and August, 1911, with the river temperatures at 73° to 80° F., the water had a distinct greenish cast, without odor; and mud taken from the bottom had a "good fresh smell." In March, 1913, however, the sludge from a deposit two feet deep a hundred yards above the Henry dam had a distinct sewage odor, and was destitute of animal life, except for one small leech, in nine two-quarts samples collected. The cooler temperature of the water (41° F.) delayed decomposition, and the comparatively strong current of the stream at the high water of this visit (10 feet at the upper gage) was doubtless rolling the bottom sediments more rapidly down the stream than in the lower stages at which our earlier observations were made. Practically the same may be said of the condition of the bottom mud from the main channel at Chillicothe at this time. The river was, however, still far below a normal unpolluted stream in oxygen ratios, and contained much more carbon dioxide. A number of tests of midstream samples made August 3 and August 29, gave us 2.33 parts per million of oxygen as a minimum and 4.59 as a maximum, with an average of 3.76 for nine determinations. Carbon dioxide ratios for this period ranged from 4.9 to 6.9 parts per million.

A heavy flooding rain which fell August 10 had the effect to

bring the oxygen ratios down, doubtless fouling the stream by flushing out sewers, scouring out tributary streams, stirring up the bottom sediments, and washing off organic debris from the surface of the country. The oxygen mean for August 3 and 4 was 4.21, and that for August 17 was 2.35, the corresponding carbon dioxide ratios being 5.8 for the first dates and 6.8 for the last.

November 8, 1911, the oxygen stood, at Chillicothe, at 10.15 parts per million, equal to 84 per cent. of saturation. Our lowest reading at this place came in July, 1912, on the 12th of which month there were but 2.05 parts per million of oxygen at Chillicothe—less than 24 per cent. of saturation. In the cooler weather of the following October and early November, with moderately high water. the ratios rose to an average of 7.5 parts per million (64 per cent. of saturation).

Between Hennepin and Chillicothe the difference in dissolved gases was but slight, and the plants and animals were virtually those of the normal population at both places and on all our visits. Our systematic collections here were made November 7, 1911, September 18 and 19, 1912, and October 22-25 of the same year. As the collections of the second year were much more detailed and extensive than those of the first, no especial account of the latter need be given.

September 18 and 19, the mussel-bar and dredges were used at various points below Henry and above Chillicothe; and October 22-25, work was done in the vicinity of Chillicothe only, with dip-nets, dredges, and small seines, no large seines, set-nets, or dynamite being brought into use at these lower stations. The river gage above the dam at Henry stood at 3.4 to 3.6.

Four hundred and ten collections were made from this section, of which 159 contained mollusks, 91 contained adult insects and insect larvæ, 42 contained *Crustacea,* and 18, fishes. Blue-green algæ were found in 10 of the Chillicothe collections—chiefly *Oscillatoria limosa* and *splendida*—usually, however, on boards and logs afloat along the edge of the stream. *Cladophora crispata* and *glomerata* were the most abundant filamentous green algæ, *Stigeoclonium tenue* and *Spirogyra decimina* var. *triplicata* coming next. Duckweed (*Lemna* and *Wolffia*), hornwort (*Ceratophyllum*), and *Elodea* were abundant higher plants. Sponges were found, as usual, on dead and living mussel shells. Oligochæte worms were rare in the bottom dredgings, as compared with those made above; planarians were occasional, and leeches occurred in fifteen collections. Of the crustaceans taken, the little "side shrimp" (*Hyalella knickerbockeri*) was

the most abundant, among algæ near the shores; *Asellus* was also common at the margin; and the river shrimp (*Palæmonetes*) and crawfishes were frequently taken. The aquatic insects occurring here were as follows:

Adults: *Gyrinus analis, Tropisternus dorsalis, T. glaber, Peltodytes edentulus, P. pedunculatus, Coptotomus interrogatus, Dryops lithophilus, Philhydrus nebulosus, Colymbetes sculptilis, Notonecta variabilis, Corixa erichsoni, C. burmeisteri; C. alternata, C. harrisii, Mesovelia mulsanti, Zaitha fluminea, Pelocoris poeyi, Ranatra fusca.* Larvæ: agrionid nymphs, *Mesothemis simplicicollis, Anax junius* (nymph), *Celithemis* nymphs, *Odontomyia, Chironomidæ,* caddis larvæ, *Chauliodes.*

Our mussel collections, representing twenty-two species, were very like those at Hennepin, differing in the addition to the Hennepin list of *Lampsilis anodontoides, Obliquaria reflexa, Plagiola elegans, P. securis, Quadrula ebena, Tritogonia tuberculata,* and *Unio gibbosus.* Among the most abundant species were *Anodonta imbecillis, Lampsilis fallaciosa, Quadrula heros,* and *Q. plicata. Sphærium transversum* was also common here, with occasional specimens of *S. striatinum* and *S. jayanum. Pisidium* was taken in four collections with the Ekmann dredge, in water six to eight feet deep.

The commonest snails were *Campeloma* and *Vivipara contectoides,* both very abundant in various situations, and *Pleurocera,* obtained mainly by the Ekmann dredge at depths varying from six to thirty feet. Additional species are *Physa gyrina, Planorbis trivolvis, P. parvus, Valvata bicarinata, Lioplax, Goniobasis,* and *Amnicola.*

Commercial fishing is carried on in the Henry-Chillicothe section on a large scale in good seasons, but much complaint has lately been made, all along this part of the river, that fishing is not so good as in former years. No systematic work for the collection of fishes was done, and the only specimens taken were caught in small seines used for collecting shore invertebrates, and are as follows:

Golden shiner, 1.	Fundulus dispar, 8.
Spot-tailed minnow, 3.	Warmouth sunfish, 1.
Silverfin, 1	Blue-gill sunfish, 7.
Shiner, 61	Large-mouth black bass, 2.
Top-minnows (young), 2.	Yellow perch, 1.

This list should be combined with the list for Hennepin to give a fair idea of our collections from this section of the river at this time, those from Hennepin having been made wholly with large seines.

We have secured further information concerning the present status of the more important fishes in this part of the upper Illinois by inquiry from reliable, experienced, and unusually well-informed fishermen of our acquaintance, especially from Herman Mehl and A. C. Wilkey, of Chillicothe, Peterman Brothers and Herbert Hall, of Henry, and F. L. Powers, for twenty-seven years a fisherman at Depue, and the following list is made up from their personal statements to us.

STATUS OF PRINCIPAL FISHES, UPPER ILLINOIS RIVER, CHILLICOTHE, HENRY, AND DEPUE, APRIL, 1913

(Statements as to numbers relate to the river only, except where otherwise specified)

Fishes	Chillicothe	Henry	Depue
Shovel-nosed sturgeon	Never taken now	Never taken now	None seen for years.
Paddle-fish	Very few; none this year	Very few; none this year	None seen for 6 or 7 years past.
Dogfish	About as numerous as ever	Becoming scarcer	Few.
Short-nosed gar	As numerous as ever	As numerous as ever	Common, but less numerous than formerly.
Long-nosed gar	As numerous as ever	As numerous as ever	Common, but less numerous than formerly.
Mud-cat	Very rare	None	None.
Channel-cat (*Ictalurus punctatus*)	Becoming scarce	Becoming scarce	Now rare; 15 years ago were taken by the ton.
Blue cat (*Ictalurus furcatus*)	None at all	Very rare or none	None taken for years.
Bullhead; 3 species	About as formerly	Not so many as formerly	Much less common than formerly; yellow bullhead now most abundant.
Common sucker	Very few	Not many	None at all.
Missouri sucker	Hardly ever seen	One this spring	None at all.
Red-horse (*Moxostoma;* various species)	Very rare	Very rare	Gone entirely; taken by the ton 15 or 20 years ago.
Native carp (*Carpiodes;* various species)	Not many	Not many	Only a few.

STATUS OF PRINCIPAL FISHES, UPPER ILLINOIS RIVER—*Continued*

Fishes	Chillicothe	Henry	Depue
Buffalo (*Ictiobus*; 3 species)	Increasingly rare	Almost gone; red-mouth the most commonly taken; less than 50 lbs. to 1000 lbs. of carp	A few red-mouth only; 8 years ago 500 lbs. of buffalo were taken in a haul of 37,000 lbs. of fish from Depue Lake, the remainder being carp; now nets in the river and lake get hardly 5 lbs. of buffalo to the thousand pounds of carp.
Eel	Very few	None	None for years.
Gizzard-shad	About as common as ever	Probably less common than formerly; now being sold for food	Not so many as formerly.
Pike	None	None	All gone.
Bluegill	About as usual	Much less common than formerly	Supply diminished greatly in last ten years.
Pumpkinseed	Scarce	Scarce	None.
Goggle-eye (*Chænobrytus gulosus*)	Not as many as formerly	A good many	Rare.
Black crappie	Rarer than formerly	Few	Very rare; now hardly a pound where a ton was taken 15 or 20 years ago.
Pale crappie	A good many at times	Less common than in previous years	A few; now hardly a pound to a ton taken 15 or 20 years ago.
Large-mouth black bass	More abundant than a few years ago	Decreasing numbers in last 3 years	Fewer than formerly.
Common perch	About the same as previously	About the same as previously	Hardly enough for a mess of fish taken all the season.
Wall-eyed pike	None	Very rare	None.
Striped bass (*Roccus chrysops*)	Usually a few only	A good many at times	But few.
Sheepshead	Hardly any; none at all this year	Rare; none at all this year	None now taken.

It should be said, with respect to the present scarcity of several of these species as compared with previous times, that the causes are probably complex, and are not to be sought in differences of the water only. As has been shown in another place*, a great stimulus to fishing operations, due to an enormous multiplication of European carp, may well have had the effect to reduce the numbers of many native species whose haunts and habits are such that they are likely to be caught by the same apparatus and operations as the carp.

A comparison of this account of Chillicothe conditions and collections with those for Morris and for Marseilles above the dam will show the main features of the effects of a sewage pollution of the river and the completeness of the biological, if not the chemical, recovery within ninety miles below.

Summary by Stations

The Sanitary Canal at Lockport.—Although the water of the canal at Lockport was comparatively clear, with an inoffensive odor even in August and September, 1911, it was not only rather heavily loaded with putrescible materials from Chicago sewage, mainly as yet undecomposed, but it was lower in oxygen content at most times than the river water either of the Des Plaines or the Illinois at any point where our tests and collections were made. In the winter however, the amount of oxygen in solution approximated the ratios of an unpolluted stream, being actually higher in February, 1912, than at any point between Lockport and Peoria. This is to be understood, of course, as due to the gradual start and slow development of the self-purification process in cold weather. Many small fishes came down the canal in summer and fall, mostly dead when they reached Lockport, although many "shiners" were still alive, but in a dying state. There were no living snails, crustaceans, or water-breathing insects in the water or on the bottom, and except for a few green algæ and other minute organisms on the riprap at the edges, the plants and animals were those of a polluted stream. These were, however, very much less abundant here in summer than in the Des Plaines beside the canal, or in the main river below.

The Des Plaines River at Lockport.—The condition and contents of the Des Plaines at Lockport, where the stream runs beside the sanitary canal, vary greatly with varying circumstances—local, seasonal, or merely meteorological. In the summer of 1911, the whole

*"The Native Animal Resources of the State." Stephen A. Forbes. Trans. Fifth Ann. Meeting, Ill. State Acad. Sci., pp. 42-43.

stream at this point was carrying polluted water, and sewage organisms were abundant across the bottom and on both sides— a fact to be attributed in part, according to our best information, to contributions of sewage from the towns above. In August and September, 1912, however, the two sides of the Des Plaines were in marked contrast. On the west side were minnows, sunfishes, green algæ, case-worms, sand-fly larvæ, *Entomostraca, Hyalella knickerbockeri,* and several kinds of mollusks, while on the east side *Sphærotilus, Carchesium, Vorticella microstoma,* and numerous other sewage organisms predominated, with fishes and clean-water mollusks conspicuous by their absence.

The Des Plaines River at Dresden Heights.—The Des Plaines at its mouth was heavily loaded with putrescible sewage materials so far advanced in decomposition that oxygen ratios were always very low. They differed however, according to season, in comparison with those of the next lower stations, being higher than these in the hottest weather and lower at lower temperatures. In July, 1911, for example, when the water of the Des Plaines contained 1.21 parts per million, that of the Illinois stood at 1.07 at Morris, and at .83 above the Marseilles dam. In November, 1912, on the other hand, the corresponding figures were 4.90 for the Des Plaines, 6.80 for the Illinois at Morris, and 7.90 at the Marseilles dam. This seasonal difference is again to be accounted for by the different effect of low and high temperatures upon the beginning and rapidity of the decomposition process in a polluted stream.

The plants and animals of the Des Plaines being of a diverse origin, were a mixture of clean-water forms from the lake and from the upper river which had not yet been overcome by their septic environment, and of species characteristic of polluted water, the latter group strongly dominating. Saprobic organisms of the midsummer microplankton were more numerous here than at any point on the river; but mingled with these were many Lake Michigan diatoms, some of which presently disappeared down stream, two continuing, however, to the lower river, where they became very abundant beyond the heavily polluted section.

There were no fishes, mollusks, crustaceans, or insect larvæ (except *Chironomus*) in the Des Plaines at Dresden Heights, although the Kankakee, but a few rods away, contained the usual biological population of a normal Illinois river.

The Kankakee at its Mouth.—Notwithstanding the fact that the Kankakee can hardly be called an uncontaminated river, its contrast with the Des Plaines, especially in summer, was very marked. When

the water of the latter stream at its mouth contained but 1.21 parts of oxygen per million, the ratio for the Kankakee was 11.21; and when the oxygen in the Des Plaines rose to 4.90 in November, that of the Kankakee was 10.90. Our lowest reading for the latter stream was 9 parts per million, in February, when the Kankakee was mainly covered with ice. Most of the oxygen ratios in the Kankakee were above those which the water will absorb directly from the air, and indicated a "supersaturation" varying from 105 to 133 per cent.

The differences between the two waters thrown together at the origin of the Illinois were reflected in oxygen ratios from the two sides of the stream just below the junction, as reported November 14, 1912—4.6 parts per million for the water of the northern or Des Plaines side, and 11.3 parts per million for the water of the southern or Kankakee side.

Morris to Marseilles.—In the seventeen-mile section of the Illinois from Morris to the upper dam the river reaches its lowest point of pollutional distress, becoming, when very hot weather coincides with a low stage of water, a thoroughly sick stream. Its oxygen is nearly all gone; its carbon dioxide rises to the maximum; its sediments become substantially like the sludge of a septic tank; its surface bubbles with the gases of decomposition escaping from sludge banks on its bottom; its odor is offensive; and its color is gray with suspended specks and larger clusters of sewage organisms carried down from the stony floor of the polluted Des Plaines, or swept from their attachments along the banks of the Illinois. On its surface are also floating masses of decaying debris borne up by the gases developing within them, and covered and fringed with the "sewage fungus" (*Sphærotilus natans*) and the bell animalcule (*Carchesium lachmanni*) usually associated in these waters. The vegetation and drift at the edge of the stream are also everywhere slimy with these foul-water plants and minute filth-loving animals. The two sides of the stream differ materially in condition at Morris, and sometimes also at Marseilles, the waters of the Kankakee and the Des Plaines not becoming completely mingled until they have passed these points.

The normal life of the stream practically disappears in the absence of oxygen; its fishes withdraw to neighboring unpolluted waters; its mollusks, crustaceans, ordinary insect larvæ and other more or less sedentary forms disappear to be replaced mainly by slime worms and *Chironomus* larvæ in the sludge; and its chlorophyll-bearing plants linger only along the edges in shallow water. With the advent of cooler weather and higher river levels, most of these marked symptoms disappear, and a few fishes may even make their

way into the stream, particularly along the south side in the vicinity of the mouths of creeks. In spring and in fall, bubbling from the bottom ceases, the odor of the water is no longer repellent, a few invertebrate animals reappear, and the oxygen ratios rise to a considerable fraction of those normal to the Kankakee. The extent of this seasonal oscillation depends, of course, upon the rainfall and temperature; and the opposite extreme is reached in winter, when midstream oxygen ratios may be fully as high as those of the summer time for Chillicothe and Peoria.

The Marseilles Dam.—The waters of the stream change but little between Morris and the Marseilles dam, the oxygen content being sometimes a little higher at one point and sometimes at the other. The mean of eight sets of determinations in six different months was 4.5 parts per million for Morris and 4.3 at Marseilles above the dam. The water is usually somewhat freer of sewage organisms at Marseilles than at Morris. This is evidently owing in part to sedimentation of suspended particles, especially the larger ones, in the slack-water above the dam, where the current, even at flood stages, was only about half a mile an hour. Both plants and animals are a little more varied and abundant at Marseilles in sheltered pockets along the banks; and a larger variety of fishes was obtained at the edge of the river close to the mouths of creeks.

The interesting feature of the Marseilles situation is the effect produced by the fall over the dam* at low water. In samples taken far enough below the fall to give the air caught in the water ample opportunity to escape, we found the ratios of dissolved oxygen in July and August, 1911, more than three times as great as those above, from one and a half to two times as great in August and September, 1912, when the water was cooler and the river higher than in the midsummer of the previous year, and 13 to 14 per cent. greater under winter conditions in February and March. This difference in oxygen doubtless had its effect upon the abundance of fishes, although these might well be expected to be more numerous below the dam than above, even if the oxygen supply were the same. The fish population was, however, small and scanty, if we may judge by our collections, consisting mainly of carp, bullheads, and the ever-present shiner in the main stream, with a considerable variety of species in shallow water near the mouths of tributaries. Black bass were reported to us to come up to the dam only in the highest water.

Ottawa and Starved Rock.—At Ottawa and Starved Rock a con-

*This dam is about 710 feet in length, and its height is about ten feet above the rock-bed of the river. (E. H. Heilbron, in letter.)

siderable progressive improvement of river conditions was manifest, due to sedimentation, to self-purification, and to dilution with cleaner tributary waters. Oxygenation increased between Marseilles below the dam and Starved Rock by 36 per cent. in August and by 14 per cent. in September, but in February it was the same at these two stations. Other evidences of sewage contamination were similarly diminished—the color of the water, the number of foul-water organisms either suspended in the water or growing at the edges, the scarcity and small variety of fishes resorting to the middle of the stream—until at Starved Rock we got our first somewhat representative collections of distinctly main-stream fishes—gizzard-shad, redhorse, carp, bullheads, and black bass. Although the slack-water sludges were scarcely changed in character from those farther up the stream, living mussels began to appear in this section in small variety, but mainly in the cleaner water of the Fox; decapod and isopod crustaceans (crawfishes and *Asellus*) came in here in some numbers; and sponges and *Bryozoa* put in an appearance in especially favorable spots. The contaminational blue-green algæ, common along shore above, practically vanished; and the chlorophyll-greens changed from *Stigeoclonium tenue* as the dominant form to species of *Cladophora,* significant of cleaner water. The degrees of this improvement varied, of course, as usual, with the temperature and the stage of water.

Spring Valley.—It was at Spring Valley, fifty-seven miles below the mouth of the Des Plaines, that, in summer time, the last visible symptoms of water pollution were to be seen. The water here had not yet recovered its normal slightly greenish tint, but was still grayish with suspended specks of septic and pollutional plankton; and it still smelled slightly of sewage, in part no doubt because of local contamination from Peru and La Salle, a few miles above. It was here that the little amphipod crustacean, *Hyalella knickerbockeri,* made its first appearance below the Kankakee, and here that the first specimens of the river shrimp, *Palæmonetes exilipes,* were collected. A considerable variety of aquatic insect larvæ, of living mussels, and of gastropod mollusks, and a much smaller proportion of dead shells, testified further to an improved environment. This was also the first place on the river in which commercial fishing operations were being carried on at any time.

These biological tests were more favorable to the Spring Valley situation than the chemical; but they are, on the whole, more reliable, if they are used with intelligence and discretion, because they show the accumulated general consequences of local conditions, favorable and unfavorable, while the chemical determination applies only

to the moment and to the place of the collection of the sample tested.

Hennepin to Henry.—At Hennepin it may be fairly said that virtually normal conditions were found, except for the state of the bottom in winter time; although it must be confessed that our chemical data, especially those for the midsummer low-water of 1911, were hardly consistent with this statement. Only 22 to 28 per cent. of oxygen saturation, with carbon dioxide running up to 7.5 parts per million, are ratios very far from those normal to an uncontaminated stream; and the highest oxygen ratio found here at any time was 82 per cent. of saturation in November. Nevertheless, the greenish tint of the water caused by the chlorophyll-bearing plankton, the virtually complete disappearance of septic and pollutional organisms, the inoffensive odor of the bottom sediments, except in winter, the great predominance of living over dead specimens of the twenty-two species of mussels taken here, and the appearance, even in hot summer weather, of suckers, crappie, warmouth, and blue-gill sunfish in the products of our seines, showed that biological tests must be added to those of chemical analysis if we are to have a fair picture of the stages of recovery in a heavily polluted stream.

Henry to Chillicothe.—In this, the last section of the upper Illinois systematically studied by us in 1911 and 1912, the process of renovation is simply carried a little farther on than in the Henry-to-Hennepin section just above. It is only in the winter time that the effects of pollution are manifest here to the senses, in the more or less rank and repellent odor of the sediments at the Henry dam, and even of those from the bottom of the open channel at Chillicothe; and it is perhaps in part to this condition that we must attribute the reported great reduction in numbers of large catfish and of buffalo from this part of the stream.

There are, indeed, many species of fishes, most of them characteristic bottom-feeders, which were formerly common in the upper part of the Illinois River, taken in quantity there by fishermen several years ago, but which are now either wanting, rare, or greatly reduced in numbers. The large catfishes, the red-horse, the buffalo, and the sheepshead are examples; and even the bullheads are said to be less common at Henry and Depue than in former years. On the other hand, the sunfishes, crappies, and bass are likewise reported to be decreasing of recent years, at least at Henry and Depue. Indeed, the reported recent reduction in numbers of the more abundant food fishes clearly becomes more pronounced as we go up stream from Chillicothe to Depue, although fishing operations are less active northward—a fact which points to unfavorable river conditions as a probable cause of this diminished yield.

General Summary of Chemical Features

The foregoing general discussion of the assemblage of conditions, chemical and biological, found at each of our observing stations in succession for the entire period of our observations, may well be supplemented by a separate recapitulation of the more important chemical features of the river situation made to include oxygen determinations from the middle and lower Illinois as well as from the upper part of the stream, and from the Mississippi near its mouth—a form of discussion which will bring out a few conclusions not easily arrived at in any other way.

July and August, 1911.—The lowest ratios of dissolved oxygen in the upper Illinois were found in July and August, 1911. When determinations at the mouth of the Kankakee varied but little from 10 parts per million, those from the midstream at Morris, nine miles below, ranged from .24 to 1.78; at Marseilles, above the dam, seven miles farther down, they averaged .67, and below the dam 2.18; and at Starved Rock, 3.18. At Chillicothe the ratios varied on different days from 2.10 to 4.21 parts per millon, with an average of 3.47. Single determinations at this lowest of our river stations yielded as little as 19.5 per cent. of saturation, and the average of all our midsummer determinations here for 1911 was but 40.8. As the Kankakee River average at this time was 112.2, it appears that during the upper ninety-three miles of its course the Illinois did not regain much more than a third of the oxygen lost to the Chicago sewage.

Heavy general rains from the 10th to the 12th in the upper Illinois basin disturbed river conditions materially, bringing the Kankakee up about six inches at its mouth and the Illinois eight inches at Marseilles and raising the levels below. Our trips for collections and chemical analyses were made on three rounds from Dresden Heights to Chillicothe, the first ending a week before these rains began, the second beginning at Dresden Heights on the date of the principal rainfall, and the third following ten days after the rains were over. Our oxygen tests are comparable for these trips at the following five points: Dresden Heights, Morris, Marseilles above the dam, Marseilles below the dam, and Chillicothe. At all these places except Morris the oxygen ratios were considerably lower after the rain than before, the decline being greatest (50 per cent.) at Chillicothe, nearly a week after the rains. Averaging the readings for these five points on the three successive trips, we got the same mean oxygen ratio, of 3.64, for both the first and the last trips, and 3.17 for the intermediate one, indicating a decline of 13 per cent. in

the oxygen of the river water after the rains, followed presently by a return to the original mean.

This effect is graphically illustrated by Figure 2, Plate LXXX, where two of the lines, representing the first and last trips, run closely parallel from Marseilles onward, while the line for the intermediate trip diverges from the others to an increasing degree from Marseilles to Chillicothe. These interesting facts may be taken as suggestive of a general fouling of the water of the stream by heavy midsummer rains coming after a long period of heat and of dry weather. A general flooding and scouring of the surface of the country, washing off of the streets of towns, and flushing out of sewers, caused by heavy rains, may be supposed to bring into the river water containing larger ratios of organic matter than the stream itself; and to these we must probably add the stirring up and carrying off of the largely organic bottom sediments of the main river.

The carbon dioxide ratios in July and August, 1911, varied from none to 2.1 for the Kankakee River, and rose as high as 12.8 at the mouth of the Des Plaines and 11.1 at Morris and Marseilles. The Illinois River ratios were lowest at Chillicothe, where, however, the mean for the three sets of determinations, August 3, 17, and 29, was 6.3 parts per million. This is to be compared with a mean of .8 for the Kankakee River for the same period.

September, 1911.—During the second week in September, 1911, when the oxygen in the midstream at Morris averaged .59 parts per million and that of the Illinois just above the outlet of Depue Lake, near Hennepin, stood at 2.65, waters from the middle of Depue Lake itself contained 11.78 parts per million, equivalent to 42 per cent. above the saturation point at the prevailing temperature of the lake water. Even the Illinois and Michigan Canal at Morris, considerably contaminated with Chicago sewage as it is, contained at this time 6.8 parts per million of oxygen when the waters of the Illinois River gave 2.03 for the south or Kankakee side, and .88 for the north bank, or Des Plaines water.

November, 1911.—The effect of a higher temperature and higher water levels was clearly shown in November, 1911, by the much higher oxygen ratio at all points on the upper Illinois. The river, having lately fallen about three feet, was still, at this time, some two feet higher than in the preceding July and August, and the temperature of the water had declined from 72.5° F., the mean of our midsummer readings, to 46°, the mean for November 1 to 8 (8:30—9 a. m.). The following is a table of parts per million of oxygen at the points where comparable tests were made.

	Mid-summer 1911	Nov. 1-8 1911
Des Plaines River	1.21	4.7
Morris	1.15	4.6
Marseilles	.67	9.9
Hennepin	2.85	9.8
Chillicothe	3.47	9.8

This is an average increase of 5.7 parts per million, or of 300 per cent., of November over midsummer ratios for this part of the Illinois River.

February and March, 1912.—A trip was made for chemical determinations February 1 to 8, 1912, from Lockport to Chillicothe, and another, March 18 to 28, from Lockport to the mouth of the Illinois at Grafton. The water temperatures averaged 34° F. on the first trip, and 35° on the second, the upper river being quite frozen over much of the time.

The oxygen determinations of these trips differ widely from those of the preceding midsummer in the much higher ratios found in the winter and in the fact that the lowest point for oxygen was very much farther down the stream. In all our midsummer trips this lowest point was reached at the Marseilles dam, but in February there was less oxygen at Chillicothe than at Marseilles, and in March, when the whole length of the river was traversed, the oxygen ratios declined down stream from Marseilles to Havana, rising then gradually to the mouth of the Illinois. At Morris the ratio of oxygen was more than six times as great in February as in midsummer; above the dam at Marseilles it was more than eight times as great; below the dam more than three times; and at Chillicothe it was 30 per cent. greater. The March ratios from Morris down were much higher still, reaching a maximum of 10 parts per million below the Marseilles dam, falling thence rapidly to Peoria (6.8), dropping a trifle only at Peoria below the outlets of the sewer system (6.5), declining slightly to Havana (6.2), and then rising steadily to the mouth of the Illinois (9.4), the water of the Mississippi standing at the same time at 10.5. In the entire distance from Lockport to Grafton the percentage of oxygen saturation on this March trip did not fall below 44 (Peru), nor rise above 75 (south shore at Morris).

July, 1912.—A single trip was made July 11 to 15, 1912, in company with the chemists of the Sanitary District of Chicago, commencing, unfortunately for our purposes, at Peru, and giving us no

data, consequently, for the interesting section of the river above Marseilles. As this trip extended to the mouth of the Illinois, it can be used from Chillicothe downward as an extension of the midsummer trips of the preceding year, which stopped at that point, to give us an idea of midsummer conditions for the whole stream. It is mainly interesting as showing an irregular but gradual rise in oxygen ratios from Chillicothe to the Mississippi, from 2 parts per million at the former place to 4.7 at Twelve-mile island, thirteen miles above the junction of the Illinois with the Mississippi. A cross-section of the latter river at Grafton, below the junction, gave 4.85 parts per million on the Illinois shore below the mouth of the Illinois River, of 7.15 at the middle of the Mississippi, and of 7.65 on the Missouri side beyond the reach of Illinois River water. Otherwise stated, while the oxygen of the water of the Illinois near its mouth lacked in July 39.5 per cent. of saturation, that of the undiluted Mississippi lacked only 1.5 per cent. The residual effect of the contamination of the former stream was thus a final loss of 38 per cent. of its oxygen.

August to October, 1912.—Our chemist made in August, September, and October, 1912, only short visits to the river to determine the oxygen ratios where biological collections were in progress, and his data are consequently in fragmentary series only. Four tests made August 21 and 22 at Marseilles, Ottawa, and Starved Rock are of interest for comparison with those made at Marseilles and Starved Rock August 24 to 26, 1911, as shown by the following table.

	1911	1912
Marseilles (above dam)	.44	1.90
" (below dam)	2.26	2.90
Ottawa		3.65
Starved Rock	3.43	4.05

The mean of the water temperatures for the 1911 period was 70.5° F., and that for August, 1912, was 6° lower; and the river levels at Morris stood some six feet higher in August, 1912, than in August, 1911. These differences of conditions are fairly reflected in the virtual doubling up of the oxygen ratios in 1912 at the contrasted points.

November, 1912.—For November, 1912, we have two trips, a fortnight apart, made the entire distance from Lockport to the

Mississippi River. The data thus obtained resemble each other closely in the general trend of the series of determinations, from a very low ratio at Lockport, with a considerable and rather steady rise to Peoria (10.5 parts per million), and nearly uniform ratios thence to the mouth of the Illinois. The later series, of November 12 to 19, runs on an average considerably higher than the earlier, November 1 to 7, but notwithstanding the saturation percentage of 87 at the mouth of the river (10.7 parts per million) it presents the strongest contrast with the Mississippi River, the midstream waters of which contained at this time 14.2 parts per million, amounting to 114 per cent. of saturation. There was no place on the Illinois on either of these trips where the oxygen ratios were less than 4.6 parts per million.

THE EFFECT OF A DAM ON DISSOLVED GASES

The fall over the Marseilles dam in the hot weather and low-water period of July and August, 1911, had the effect to increase the dissolved oxygen more than four and a half times, raising it from an average of .64 parts per million to 2.94 parts. On the other hand, with the cold weather, high oxygen ratios, and higher water levels of February and March, 1912, and the consequent reduced fall of a larger volume of water at Marseilles, the oxygen increase was only 18 per cent.—from 7.35 parts per million above the dam to 8.65 parts below; and in August and September, 1912, the weather being still cooler and the water lower than in the midsummer of the previous year, the increase was only 77 per cent.—from 2.05 parts per million above the dam to 3.62 parts below. It should be noted, however, that this beneficial effect is greatest when it is most needed—when the pollution is most concentrated and decomposition processes are most active. In the absence of a dam at this point, the recovery of oxygen used up in decomposition would be greatly retarded in midsummer, and heavily polluted water would be carried much farther down the stream.

A reverse but much less pronounced effect is produced at the dam upon the carbon dioxide content of the waters of the stream. This was diminished, in the summer of 1911, from 8.2 parts per million above to 6.48 parts below the dam—a reduction of 21 per cent. The ratio of loss of carbon dioxide was thus only a seventeenth part of the ratio of gain in oxygen. A similar statement may be made concerning losses and gains of these gases for the upper Illinois River as a whole. Taking the means of the oxygen ratios at each point for the period from July 28 to August 29, 1911, we find them rising

from 1.35 at Morris to 3.82 at Chillicothe—an increase of 183 per cent.; while the carbon dioxide drops from 7.7 to 6.1, a loss of 22 per cent.—the greater part of both changes occurring, in fact, at the Marseilles dam. It will thus be seen that in judging of the biological effects of pollution and self-purification of the stream, we must take note of the fact that a given increase or decrease in carbon dioxide is accompanied by a loss or gain in oxygen from eight to seventeen times as great.

SEASONAL PHASES OF CHEMICAL CONDITION

The combination of our tables and our graphs by seasons, and a comparison of these sets of seasonal data one with another, brings out clearly three phases in river condition which may be called the midsummer, fall, and winter phases, and implies also a fourth or spring phase, for which we have at present no data. The midsummer and the winter phases represent, of course, the extremes between which the fall and spring conditions come as intermediate or transition stages. The midsummer phase, with its high temperatures and low stage of water, is characterized by a concentrated pollution and an early and rapid decomposition and deoxygenating process, with lowest oxygen readings at Morris and above the dam at Marseilles, followed by a sudden increase of oxygen below the dam and a gradual rise in ratios thence down the stream to its mouth. The winter phase contrasts with this by a delay of decomposition such that the oxygen ratio is highest at Marseilles, declines slowly to the middle of the river's course, (about at Havana,) and then rises gradually to its mouth. In the autumnal transition phase the oxygen ratio is at its lowest point in the Dresden Heights-Marseilles section, although much higher there than in midsummer, rises thence slowly to Peoria, and continues on an approximately level line to the mouth of the Illinois. In the spring phase a transition in the opposite direction probably gives somewhat similar results, modified, however, by the spring floods, which are usually much larger than those resulting from the fall rains, and by differences in the antecedent seasonal conditions from which this spring transition makes its start.

These periodical changes in the distribution of oxygen and carbon dioxide within the stream are, of course, consequent upon seasonal differences in temperature and stage of water, influenced considerably by the upper dam, at Marseilles; and the above descriptions may perhaps need modification to make them applicable to notably unusual years.

ADDITIONAL DATA UPON THE RIVER SLUDGES

Since this manuscript was prepared we have received from the chemists of the Water Survey a report on the following series of nine sludge samples collected in March, 1913, with a view to determining the winter condition of the river sediments throughout the length of the stream. It will be seen that they agree in the main with the short series on page 00 to the effect that a marked change occurs between Marseilles and Henry, and that they show a gradual improvement in respect to organic contents in the samples obtained below Peoria.

ANALYSIS OF SLUDGES FROM THE ILLINOIS RIVER

Date collected 1913	Source, water temperature, and odor	Specific gravity	Moisture	Per cent. in terms of dry matter			
				Nitrogen	Loss on ignition	Fixed matter	Ether soluble
March 18	Drainage Canal, Lockport; 37° F; fecal.	1.20	71.2	.55	22.2	77.8	2.67
17	Illinois River, Morris; 36° F; fecal.....	1.35	53.6	.51	16.2	83.8	1.12
19	Illinois River, Marseilles; 40° F; fecal	1.24	44.3	.67*	10.	90.	1.07
20	Illinois River, Henry; 41° F; disagreeable.....	1.28	63.	.39	12.1	87.9	.40
26	Illinois River, Chillicothe; 39° F; disagreeable...	1.38	48.3	.39	11.6	88.4	.36
April 5†	Illinois River, Peoria Narrows..	1.69	32.1	.14	6.8	93.2	.28
March 25	Illinois River, Copperas Creek; 43° F; earthy ...	1.58	40.2	.15	4.8	95.2	.11
24	Illinois River, La Grange; 43° F; earthy.....	1.57	37.4	.20	5.3	94.8	.11
22	Illinois River, Pearl; 41° F; earthy..... ..	1.77	29.8	.12	3.2	96.8	.18

*Large numbers of sewage worms in this sample account for the high nitrogen content.
†Date received at laboratory.

Table of Dissolved Oxygen and Carbon Dioxide, Illinois River and Related Waters, 1911 and 1912

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Carbon dioxide, p.p.m.	Remarks
		1911								
Lake Michigan	Chicago	July 18	12 m.	3 ft	20.3	68.5	7.91	87.4		39th St. pier
" "	"	"	3:30 p.m.	3 ft	21.4	70.5	9.25	103.6		39th St. pier
Illinois River	Morris	July 22	10 a. m.	5 ft	24.8	76.4	.30	3.4		Midstream
" "	"	"	1:30 p.m.	5 ft	25.	77.	.26	3.1		"
" "	"	"	4 p.m.	5 ft	24.5	77.	.17	2.0		Midstream
" "	"	"	10 a.m.	3 ft	24.5	77.	.04	0.5		40 ft. from south bank
" "	"	"	1:30 p.m.	3 ft	25.	77.	.28	3.3		" " "
" "	"	"	4 p.m.	3 ft	24.5	77.	.31	3.5		" " "
Kankakee River	Dresden Heights	July 24	2 p.m.	18 in	20.0	68.	9.91	107.9		Midstream
" "	" "	" 26	2 p m.	12 in	22.	72.	11.21	126.8	2.1	12 ft. from east bank
Des Plaines River	"	" 27	10 a.m.	5 in	20.	68.	1.25	13.6	12.8	At the dam
" "	" "	" 27	1:30 p.m.	5 in	20.	68.	1.17	12.7	12.8	At the dam
Illinois River	Morris	" 28	7:30 a.m.	5 in	20.	68.	1.24	13.5	8.2	Midstream
" "	"	" 28	1:30 p.m.	5 in	20.	68.	.91	9.9	14.1	Midstream
" "	Marseilles	" 30	9:30 a.m.	9 ft	21.	70.	.80	8.9	5.9	Midstream, above dam
" "	"	" 30	9:30 a.m.	18 in	21.	70.	.86	9.5	5.9	" " "
" "	"	" 31	10 a.m.	18 in	21.6	71.2	2.64	29.9	5.8	¾ mile below dam; 8 ft. from shore.
" "	Peru	Aug. 2	8:30 a.m.	18 in	21.9	71.8	3.20	36.	6.9	Above canal
" "	"	" 2	9 a.m.	18 in	21.9	71.8	3.17	35.8	6.6	At bridge, south side
" "	"	" 2	1:30 p.m.	18 in	22.	72.	3.51	39.6		" "
" "	Chillicothe	" 3	11 a.m.	10.5 ft	24.4	76.8	4.29	50.4	5.9	¼ mile above landing
" "	"	" 3	11 a.m.	18 in	24.4	76.8	4.59	53.9		" " "
" "	"	Aug. 4	9:30 a.m.	10.5 ft	24.4	76.8	3.71	43.6	6.	¼ mile above landing
" "	"	" 4	9:30 a.m.	18 in	24.5	77.	4.24	50.3	5.6	" " "
Kankakee River	Dresden Heights	Aug. 10	10:30 a.m.	18 in	26.	79.	8.67	105.9	.7	⅛ mile above mouth, 30 ft. from east bank
" "	" "	" 10	2:30 p.m.	18 in	28.	83.	10.54	133.1		Same location as above
Illinois River	Morris	" 11	8 a.m.	18 in	22.	72.	1.85	20.9	8.5	Midstream

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Carbon dioxide, p.p.m.	Remarks
Illinois River ..	Morris.	Aug. 11	1:30 p.m.	18 in	22.	72.	1.72	19.5	6.9	Midstream
" "	Marseilles.	" 12	8:30 a.m.	18 in	22.	72.	.98	11.	11.2	¼ mile above dam
" "	"	" 14	8:15 a.m.	18 in	22.5	73.	.48	5.5	11.1	¼ mile above dam after heavy rain; river up 8 in.
" "	"	" 14	9:15 a.m.	4 in	22.5	73.	1.65	18.9	8.7	¾ mile below dam; 3 ft. from bank
" "	Starved Rock....	" 15	9:45 a.m.	12 in	25.	77.	2.58	30.9	7.4	Near south side
" "	"	" 15	1 p.m.	12 in	25.	77.	2.62	31.4		" " "
" "	"	" 15	10:45 a.m.	12 in	25.	77.	3.18	38.		Near north side
" " ..	" ...	" 15	1:30 p.m.	16 in	25.	77.	3.34	40.	7.3	" " "
" "	Hennepin.....	" 16	9:30 a.m.	18 in	25.5	78.	2.22	26.8	7.5	Midstream
" " ..	"	" 16	1 p.m.	18 in	26.5	80.	2.27	28.	7.5	"
" "	Chillicothe.	" 17	9 a.m.	18 in	26.	79.	2.33	28.4	6.7	"
" "	"	" 17	1 p.m.	18 in	26.	79.	2.37	28.9	6.9	"
Kankakee River.	Dresden Heights.	Aug. 21	10:30 a.m.	18 in	23.	73.	8.47	97.6		30 ft. from east bank
" "	"	" 21	2 p.m.	18 in	24.2	76.4	10.15	119.3		" " "
Illinois River....	Morris.	" 22	9:30 a.m.	18 in	22.5	73.	1.37	15.7	6.7	Midstream
" "	"	" 23	8 a.m.	18 in	22.6	73.2	1.47	17.	6.4	"
" "	Marseilles.	" 24	8:15 a.m.	18 in	21.7	71.4	.55	6.2	8.0	" above dam
" "	"	" 25	12:15 p.m.	18 in	21.	70.	.78	8.6	8.6	" " "
" "	"	" 24	9 a.m.	9 in	21.5	71.	1.73	19.4	5.9	¾ mi. below dam; 6 ft. from bank
" "	"	" 25	1 p.m.	9 in	21.2	70.4	2.80	31.	6.2	Below dam; 6 ft. from bank
" "	Starved Rock....	" 26	9:15 a.m.	9 in	21.	70.	3.07	34.	5.8	South side
" "	" ...	" 26	10:30 a.m.	12 in	21.5	71.	3.72	41.7	5.4	North side
" "	"	" 26	12:30 p.m.	12 in	22.	72.	3.87	43.8	5.5	North side
" "	Hennepin.....	" 28	9:30 a.m.	18 in	22.	72.	3.28	37.1	6.4	Midstream
" "	"	" 28	2 p.m.	18 in	23.2	74.4	3.62	41.7	6.0	"

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Carbon dioxide, p.p.m.	Remarks
Illinois River	Hennepin	Aug. 28	9:45 a.m.	18 in	22.	72.	3.50	39.6	6.4	50 ft. from east bank
" "	"	" 28	2:15 p.m.	18 in	23.5	75.	3.50	40.7	6.8	" " " "
" "	Chillicothe	" 29	9:30 a.m.	18 in	22.5	73.	3.95	45.1	6.3	Midstream
" "	"	" 29	3 p.m.	18 in	22.8	73.6	4.28	49.4	6.1	"
" "	"	" 29	12 m.	18 in			4.60		4.9	East side of island
Illinois River	Morris	Aug. 31	8:30 a.m.	18 in	20.	68.	1.05	11.4		Midstream
" "	"	" 31	1:30 p.m.	18 in	22.	72.	1.18	13.3	7.4	"
" "	"	" 31	8:30 a.m.	1 in	20.8	69.6	3.5	38.9	7.2	4 in. deep near shore; over Stigeoclonium
" "	"	" 31	1:30 p.m.	1 in	22.3	72.6	6.1	69.	4.2	4 in. deep near shore; over Stigeoclonium
" "	Marseilles	Sept. 1	8:30 a.m.	18 in	21.	70.	.58	6.4	7.4	Above dam
" "	"	" 1	9:15 a.m.	6 in	21.2	70.4	5.90	65.4	5.8	⅛ mile below dam
" "	Ottawa	" 2	11:30 a.m.	6 in	23.	73.	4.75	54.8		Near south shore, above Fox; water 2 feet deep
" "	"	" 2	1:45 p.m.	6 in	23.7	75.4	5.50	64.6	4.6	Near south shore, above Fox; water 2 feet deep
" "	"	" 2	2:45 p.m.	6 in	23.8	75.6	5.82	68.4	4.2	Near south shore, above Fox; water 2 feet deep
" "	"	" 2	3:40 p.m.	6 in	23.7	75.4	5.70	70.	4.35	Near south shore, above Fox; water 2 feet deep
" "	"	" 2	4:30 p.m.	6 in	23.7	75.4	5.42	63.7	4.7	Near south shore, above Fox; water 2 feet deep
" "	"	" 2	5:30 p.m.	6 in	23.7	75.4	4.87	56.9	5.5	Near south shore, above Fox; water 2 feet deep
" "	Morris	" 8	2 p.m.	18 in			.70			Midstream
" "	"	" 9	7:30 a.m.	18 in			.50			"
" "	"	" 9	1:30 p.m.	18 in			.68			"

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Carbon dioxide, p.p.m.	Remarks
Illinois River ...	Depue	Sept. 11	11:15 a.m.	18 in	22.5	73.	2.65	30.3	7.16	Above outlet of lake
Depue Lake.....	"	" 11	2 p.m.	18 in	24.8	77.6	12.92	155.		Middle of lake
Illinois River	Morris.	Sept. 13	7:30 a.m.	18 in	20.8	69.6	2.03	21.4		Near south bank
" "	"	" 13	11 a.m.	18 in	21.2	70.4	.88	9.7		Near north bank
Ill. Mich. Canal..	"	" 12	5 p.m.	18 in			6.80			
Drainage Canal..	Lockport.....	Nov. 1	10 a.m.	2 ft		50.	2.5	22.1		
							2.5	22.1		East bank of canal
Des Plaines R ...	"	" 2	10 a.m.	10 in		51.	5.2	46.		Near east bank; water 1 foot deep
							4.7	42.		
Illinois River ..	Morris.	" 3	9 a.m.	2 ft		41.	3.6	28.1		
							3.7	28.9		Midstream
" "	"	" 3	2 p.m.				5.5			
							5.6			Probably farther from north bank
" "	"	" 3	9 a.m.	2 ft			10.8	84.4		Near north bank
" " ...	Marseilles. ...	" 4	9 a.m.	2 ft		43.	10.	80.6		Above dam
" " . .	Hennepin	" 7	8:30 a.m.	2 ft		46.	9.8	82.3		
							9.7	81.5		Midstream
" " ..	Chillicothe.	" 8	10 a.m.	2 ft		45.	10.2	84.4		
							10.1	83.6		Midstream
		1912								
Illinois River	Morris	Feb. 16	10 a.m.		2.	35.6	7.2	51.9		
			3 p.m.		1.	33.8	7.6	53.2		
							7.5	52.5		South shore
" "	"	" 16	10 a.m.	2 ft	2.	35.6	7.2	51.9		
			3 p.m.		1.	33.8	6.9	48.3		
							6.8	47.6		Center of channel

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n	Remarks
Illinois River	Morris	Feb. 16	10 a.m.	8 ft	2.	35.6	7.2	51.9	
			3 p.m.		1.	33.8	6.3	44.1	Center of channel
" "	"	" 16	10 a.m.		2.	35.6	6.6	47.5	
			3 p.m.		1.	33.8	6.3	44.1	North shore
Des Plaines R...	Lockport.....	" 17			1.5	34.7	8.6	61.2	
							8.9	63.3	
Drainage Canal..	"				1.	33.8	9.4	65.8	
							9.2	64.4	
Kankakee River.		" 19			.5	32.9	9.	62.	
							9.1	62.7	
Illinois River	Marseilles	" 20			3.	37.4	6.3	46.7	South shore, above dam
" " ...	"	" 20			3.	37.4	5.9	43.7	Center of channel
" " ...	"	" 22			.5	32.9	7.1	48.3	North shore
" " ...	"	" 22			.5	32.9	7.3	49.6	Below dam
" " ..	Starved Rock...	" 23			.5	32.9	7.3	50.4	
" "	Chillicothe.	" 24			2.	35 6	5.	36.	
Des Plaines R. ..	Lockport	Mar. 18			2.5	36.5	6.5	47.5	
Chicago Drainage Canal.....	"	" 18			3.	37.4	6.3	46.7	
Illinois River....	Morris	" 19			1.5	34.7	10.4	73.8	South shore
" " ...	"	" 19			1.5	34.7	9.2	65.4	North shore
" " ...	Marseilles.	" 21			0.0	32.	8.8	59.8	Above dam

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River	Marseilles	Mar. 21			0.0	32.	10.	68.	Below dam
" "	Chillicothe	" 22			0.0	32.	7.2	49.	
" "	Peoria	" 23			0.0	32.	6.8	46.3	Above sewer outlet
" "	"	" 23			0.0	32.	6.5	44.2	Below sewer outlet
" "	Havana	" 25			2.	35.6	6.2	44.6	
" "	Beardstown	" 26			1.5	34.7	7.7	54.7	
" "	Pearl	" 27			2.	35.6	9.3	67.	
" "	Grafton	" 28			3.	37.4	9.4	69.7	
Mississippi R	"	" 28			3.	37.4	10.5	77.8	
Ill.–Miss. Canal		July 11	8 a.m.		25.	77.	4.3	51.2	At junction with Illinois River
Illinois River	Peru	" 11			25.	77.	2.7	32.2	
" "	Spring Valley	" 11	9 a.m.		25.	77.	2.		
							1.9	23.3	
" "	Marquette	" 11	9:30 a.m.		25.	77.	1.4		
							1.6	17.9	
" "					25.	77.	1.4		
							1.5	17.3	Opposite Ill.-Miss. Canal
Ill.-Miss. Canal L.L.					28.	83.	5.2	65.7	
Illinois River	Hennepin	July 11	10:45 a.m.		25.	77.	1.8	21.5	
" "	Twin Sister Islands	" 11	11:15 a.m.		26.	79.	2.3		
							2.2	27.4	
Mud Lake		" 11			26.	79.	7.70	93.8	1000 ft. from Ill. River
Illinois River		" 11			26.	79.	7.80	94.8	Mouth of Mud Lake
" "		" 11			26.	79.	2.60	31.6	½ mile below Mud Lake

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River	Henry	July 11	12:30 p.m.		26.	79.	2.1		
							2.5	28.	Above dam
" "	"	" 11			26.	79.	2.4	29.2	Below dam
" "	Lacon.	" 11	2 p m.		28.	83.	2.1		
							2.3	27.8	
" "		" 11	2:30 p.m.		28.	83.	2.7	34.1	Opposite Babb's Slough
" " ..	Chillicothe.....	" 11			28.	83.	2.5	31.6	East bank; cross section
" " ...	"	" 11			28.	83.	2.7		
							3.	36.	Middle, cross section
" " ...	"	" 11			28.	83.	2.8	35.4	West bank; cross section
" " ...	"	" 12	9:15 a.m.		25.	77.	2.		
							2.1	23.9	
Illinois River....		July 12			25.	77.	1.9	22.7	Opposite entrance to Peoria Lake
" "		" 12	10 a.m.		25.	77.	4.5	53.9	East bank, below Partridge Island
" "		" 12			25.	77.	2.		
							2.1	23.9	Middle, below Partridge Island
" " ...		" 12	10:15 a.m.		25.	77.	1.7	20.3	West bank, below Partridge Island
" " ...		" 12			25.	77.	3.2	38.2	Opposite Spring Bay
" " ...		" 12			25.	77.	5.3		
							5.4	62.	West bank, below Horse Haw Slough
" " ...		" 12			25.	77.	3.7	44.2	Middle, below Horse Haw Slough

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912—*Continued.*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River	Peoria Heights..	July 12	12 m.		25.	77.	4.3		
							4.5	52.5	
" "	Averyville.....	" 12			26.	79.	6.9		
							6.8	83.4	East bank; cross section
" "	"	" 12			26.	79.	5.3	64.5	Middle; cross section
" " ...	"	" 12			26.	79.	5.9	71.8	West bank; cross section
" " ...	Peoria	" 12	3 p.m.		26.	79.	7.2		
							7.0	86.4	West bank, foot of Liberty street
" "	"	" 12			27.	81.	8.1		
							7.8	98.6	Middle, foot of Liberty street
" "	Wesley..... ...	" 12			27.	81.	7.		
							6.7	85.	
" "	Pekin	" 12			27.	81.	5.4	67.	Below highway bridge
" " ...	"	" 12			27.	81.	6.4	79.3	East bank; public landing
" "	"	" 12			27.	81.	6.6		
							6.5	81.2	Below all distilleries
" " ...	"	" 12			27.	81.	6.1	75.6	At point of dung discharge
" "		" 12			27.	81.	5.6	69.4	Between Pekin and Mackinaw River
" " ...		" 13	5 p.m.		27.	81.	5.2	64.4	Above Mackinaw River
" " ...		" 13			27.	81.	5.4	67.	Below Mackinaw River
" " ...		" 13	7:45 a.m.		26.	79.	5.3	64.5	Above Mackinaw River
" " ...	Kingston Mines..	" 13			26.	79.	4.1		
							4.6	52.3	Opposite the town
" " ...		" 13				79.	3.6		
					26.		3.3	42.	At 141-mile Point
" "	Copperas Creek..	" 13				79.	3.8		
					26.		4.	47.4	Above dam

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River....	Copperas Creek..	July 13			26.	79.	3.7	45.	Below the dam
" "	Liverpool.....	" 13	10:15 a.m.		27.	81.	3.6	44.6	
" "		" 13			29.	85.	4.6		
							4.9	61.1	Above Spoon River
Spoon River.....		" 13			28.	83.	5.7		
							5.6	71.3	At mouth
Illinois River...		" 13			27.	81.	3.7	45.9	Below Spoon River
" "	Havana.....	" 13	11:30 a.m.		27.	81.	3.6		
							3.7	45.2	Middle
" "	Grand Island....	" 13		6 ft	29.	85.	3.3	42.5	Above
" " ...	" " ...	" 13		2 ft	29.	81.	3.4		
							3.6	45.	"
" "	" "	" 13			28.	83.	4.9		
							4.7	60.6	Below
" "	Sharp's Landing.	" 13			27.	81.	4.7		
							4.4	56.4	
" "		" 13			27.	81.	6.2		
							5.9	76.2	At Panther Slough
" "		" 13			27.	81.	6.2		
							6.3	77.4	Below Island
" "	Browning.....	" 13	4:30 p.m.		27.	81.	3.8	47.1	
" "		" 13	5 p.m.		27.	81.	3.7		
							3.6	45.2	Opposite Big Lake
" "	Beardstown.....	" 13	5:30 p.m.		29.	85.	3.7	47.6	West bank; cross section
" "	"	" 13			28.	83.	4.8	50.6	Middle; cross section
" "	"	" 13			28.	83.	5.3	67.	East bank; cross section
" "	"	" 14	8:10 a.m.		27.	81.	4.2	52.	One mile below

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n	Carbon dioxide, p.p.m.	Remarks
Illinois River		July 14	8:45 a.m.		27.	81.	3.8	47.1		One mile below Crooked Creek
" "	LaGrange	" 14			28.	83.	3.8			
							3.7	47.4		Above dam
" "	"	" 14	9:45 a.m.		28.	83.	4.6			
							4.5	58.1		Below dam
" "	Meredosia	" 14	10:30 a.m.		28.	83.	4.6			
							4.4	56.8		
" "	Naples	" 14	11:15 a.m.		27.	81.	4.4	54.6		
" "	Valley City	" 14			27.	81.	4.7	58.3		
" "	Florence	" 14	12:30 p.m.		28.	83.	4.6			
							4.7	58.7		
" "	Bedford.	July 14	1:15 p.m.		29.	85.	4.6	59.2		
" "	Pearl	" 14			30.	86.	4.7			
							4.8	62.2		
" "	Kampsville	" 14	3:30 p.m.		30.	86.	4.3	56.4		Above dam
Illinois River	"	" 15	8 a.m.		28.	83.	4.3	54.3		Above dam
" " . ..	"	" 15	8:30 a.m.		28.	83.	4.6	58.1		Below dam
					29.	85.	4.6			
							4.7	59.8		At head of Diamond Island
" " . ..	Hardin.	" 15	9:30 a.m.		29.	85.	4.7	60.5		
" "		' 15	10:15 a.m.		29.	85.	4.8			
							4.7	60.5		Above 12-mile Island
Mississippi R ..	Grafton	" 15	11:45 a.m.		29.	85.	4.8			
							4.9	62.4		East bank; cross section
" "	"	" 15			29.	85.	7.1			
							7.2	92.		Middle; cross section
" "	"	" 15	12 m.		29.	85.	7.6			
							7.7	98.5		West bank; cross section

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912— *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n	Remarks
Des Plaines R...	Lockport..	Aug. 6	1 p.m.	12 in	24.	76.	12.1	142.	Midstream; river very shallow
Drainage Canal..	Lockport.....	" 6	8 p.m.		22.5	73.	.5	5.	South side
Kankakee River.	Dresden Heights.	" 7	10 a.m.		21.5	71.	9.5	107.	Cloudy; shore sample
Des Plaines R...	" " .	" 7	11 a.m.		22.	72.	2.1	24.	" " "
Illinois River....	Morris.....	" 8	7 a.m.		20.5	69.	4.5	50.	South side; 30 ft. from bank
" "	"	" 8	8 a.m.		21.5	71.	2.1	23.	Midstream
" " ...	"	" 8	9 a.m.		22.	72.	.8	9.	North side; 30 ft. from bank
" "	Marseilles.....	" 8	2 p.m.		23.5	75.	1.9	22	Midstream; above dam
" "	"	" 8	12 m.		23.5	75.	4.4	51.	Below dam
" " ...	"	Aug. 21	1:30 p.m		23.	73.	1.9	21.9	
							1.8	20.8	Midstream; above dam
" " ...	Marseilles.....	" 21	2:30 p.m.		23.	73.	1.6	18.5	
							1.5	17.3	South side
" "	"	" 21			23.	73.	1.7	19.6	
							1.8	20.8	North side
" " ...	"	" 21	4:30 p.m.		23.	73.	2.9	33.5	Below dam
" " ..	Ottawa	" 22	3 p.m.		23.	73.	3.9	45.	
							4.	46.2	South side; above Fox River
" " ..	"	" 22			23.	73.	3.4	39.2	
							3.3	38.1	North side
" " ...	Starved Rock....	" 22	10 a.m.		23.	73.	4.5		
							4.4		North shore
" "	" "	" 22			23.	73.	3.7	42.7	
		" 22					3.6	41.5	South shore
Illinois River ...	Hennepin.....	Sept. 6	11 a.m.		26.	79.	2.4	29.3	
							2.2	26.8	
							2.3	28.	Midstream

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n	Remarks
Illinois River....	Starved Rock....	Sept. 6	5 p.m.		26.	79.	2.4	29.3	
							2.5	30.5	South shore
" "	" "	" 6	5:30 p.m.		26.	79.	2.7	32.9	
							2.6	31.7	
							2.8	34.1	North shore
" "	Chillicothe.	" 7	9 a.m.		26.5	80.	2.7	33.3	
							2.6	32.1	
							2.7	33.3	Midstream
Des Plaines R...		" 26	10 a.m.		18.	65.	1.1	11.6	
							1.	10.4	Just above junction with Kankakee
Kankakee River.		" 26	11 a.m.		16.	61.	10.5	105.6	
							10.3	103.6	Just above junction with Des Plaines
Illinois River....	Morris	" 27	10.a.m.		17.	63.	1.8	18.4	
							1.7	17.4	Midstream
" "	"	" 27	10 a.m.		17.	63.	3.7	37.9	
							3.6	36.8	South side
" "	"	" 27	10:30 a.m.		17.	63.	1.8	18.4	
							1.7	17.4	North side
" "	Marseilles.	" 27	1:30 p.m.		17.	63.	2.1	21.5	
							2.3	23.6	Above dam
" "	"	" 27	3 p.m.		17.	63.	*A* 4.3	44.1	
							4.4	45.1	Below dam
							B 3.8	39.	

(*Note.*—These samples below dam are very unsatisfactory, as they were taken from shore near algæ.)

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp, F.	Dissolved Oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River ...	Starved Rock	Sept. 28	8:30 a.m.		17.	63.	5.3	54.3	
							5.1	52.3	North shore
" "	" "	" 28	8 a.m		16.	61.	4.8	48.3	
							4.6	46.3	South shore
Illinois River	Marseilles.	Oct. 11	10:30 a.m.		16.	61.	1.	10.1	
							.9	9.	Above dam; midstream
" "	Starved Rock....	" 11	2:30 p.m.		16.	61.	3.5	35.2	
							3.4	34.2	
							3.6	36.2	South shore
" "	" " ...	" 11	3 p.m.		16.	61.	4.8	48.2	
							4.7	47.2	North shore
" "	Hennepin	" 12	10 a.m.		15.	59.	5.5	54.2	
							5.6	55.2	Midstream
" " . ..	Chillicothe.	" 24	9:30 a.m.		12.	54.	6.5	60.	
							6.4	59.1	
							6.3	58.2	Midstream
" "	Hennepin	" 24	4:30 p.m.		12.	54.	6.3	58.2	
							6.5	60.	
							6.4	59.1	Midstream
" "	Chillicothe.	" 25	2 p.m.		12.	54.	6.	55.4	
							6.2	58.2	Midstream
" " . ..	Starved Rock...	" 26	9:30 a.m.		10.5	51.	6.1	54.5	
							6.2	55.4	North side
" "	" "	" 26	10 a.m.		11.	52.	5.	45.1	South side

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Drainage Canal..	Lockport.....	Nov. 1	5 p.m.		9.	49.	.4	3.5	9th st. bridge
Des Plaines R...	"	" 1	5:30 p.m.		9.	49.	4.5		
							4.6	38.8	" " "
Illinois River....	Morris.....	" 2	7:30 a.m.		9.	49.	4.8	41.4	North side
" " ...	"	" 2			9.	49.	6.5	56.	South side
" " ...	Marseilles.....	" 2	10 a.m.		9.	49.	4.7		
							4.6	39.9	Above dam
Fox River.....	Ottawa..... ..	" 2	2:30 p.m.		6.5	44.	10.8		
							11.1		
							11.	81.4	
Illinois River....	"	" 2	3:30 p.m.		9.	49.	5.8		
							5.7	49.1	Above Fox River
" "	Hennepin.....	" 3	10 a.m.		8.	47.	7.2		
							7.	60.1	
" "	Chillicothe.	" 3	2:30 p.m.		8.	47.	7.6		
							7.8	64.8	
" " ...	Peoria.....	" 4	8 a.m.		8.	47.	10.6		
							10.3	88.3	Above sewer outfalls
" "	"	" 4	10 a.m.		8.	47.	9.5		
							9.6		
							9.7	80.8	Below all distilleries and sewers
" "	Havana.....	" 4	2 p.m.		8.	47.	9.7		
							9.6		
							9.4	80.8	
" "	Beardstown.....	" 5	9:30 a.m.		8.	47.	9.5		
							9.1		
							9.4	78.5	
" " ...	Pearl	" 6	1:30 p.m.		9.	49.	10.7		
							10.4	90.6	

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River	Grafton.....	Nov. 7	11 a.m.		9.	49.	9.		
							9.1	77.9	At mouth
Mississippi R....	"	" 7	12 m.		9.	49.	10.6		
							10.9	92.1	Above mouth of Illinois
Chicago River...	Chicago.....	" 12	9 a.m.		11.	52.	9.9		
							10.1	90.2	Halsted and 39th sts.
" " ...	"	" 12	9:30 a.m.		11.	52.	9.7	87.5	"Forks," east and west forks of south arm of south branch of Chicago River.
" " ...	"	" 12	9:45 a.m.		11.	52.	5.4	48.7	Bridgeport, south arm at junction with south branch of Chicago R.
Ogden ditch.	Chicago.....	" 12	10 a.m.		10.5	51.	8.9	79.5	At Western avenue
	"	" 12	11:30 a.m.		10.	50.	8.8	75.9	South branch at Loomis street
	"	" 12	12 m.		9.5	50.	10.6	92.3	South branch at Van Buren street
Lake Michigan ..	Chicago.....	" 12	12:30 p.m.		9.	49.	12.4		
							12.1	105.2	Opposite U.S. Life Saving Station
	"	" 12	1 p.m.		10.3	50.6	6.7	59.9	North branch, Chicago avenue
	"	" 12	1 p.m.		10.	50.	8.9	88.7	North branch, North av.
	"	" 12	1:15 p.m.		10.5	51.	10.		
							9.8	87.7	North branch, Diversey Boulevard

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
	Chicago	Nov. 12	1:30 p.m.		10.	50.	10.	87.1	North branch, ½ mi. below Lawrence avenue
Drainage Canal	"	" 13	12 m.		11	52.	7.	63.1	Kedzie avenue
" "	Summit	" 13	1 p.m.		10.	50.	7.	62.	Santa Fe bridge
" "	Willow Springs	" 13	1:30 p.m.		10.	50.	5.	44.3	
" "	Lemont	" 13	2 p.m.		10.	50.	3.1	27.4	
" "	Lockport	" 13	3 p.m.		10.	50.	2.2	19.5	9th st. bridge
" "	"	" 13	3:30 p.m.		10.	50.	2.8	24.7	At locks
Illinois River	Morris	" 14	7:30 a.m.		8.	47.	6.5	54.6	North side
" "	"	" 14	7:30 a.m.		8.	47.	6.8	57.2	Midstream
" "	"	" 14	7:30 a.m		8.	47.	8 7	73.1	South side
Mazon Creek		" 14	7:30 a.m.		9.	49.	8.2	70.8	At mouth
Illinois River		" 14	8 a.m.		8.5	48.	6.2	53.	Kinney's Island
" "		" 14	8 a.m.		8.5	48.	5.4	46.2	Perry's Island, north side
" "		" 14	8:30 a m.		8.	47.	6.1	51.3	Perry's Island, midstream
" "		" 14	8:30 a.m.		8.	47.	9.5	80.	Perry's Island, south side
Au Sable Creek		" 14	9 a.m.		5.5	42.	10.6	83.9	At mouth
Illinois River		" 14	9:30 a m.		7.	45.	4.5	36.9	At E. J. & E. R. R. bridge
" "	Dresden Heights	" 14	11 a.m.		7.	45.	4.6	37.7	North side
" "	" "	" 14	11 a.m.		6.	43.	11.3	90.5	South side
Des Plaines R	" "	" 14	11 a.m.		7.	45.	4.9	40.3	At mouth
Kankakee River	" "	" 14	11 a.m.		6.	43.	11.		
							10.8	87.2	At mouth
Illinois River	Marseilles	" 14	4 p.m.		8.	47.	7.7		
							8.	66.4	Above dam
Ill. & Michigan Canal	LaSalle	" 15	9 a.m.		4.5	40.	11.6		
							11.5	77.1	Lowest lock

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Ill. & Michigan Canal	LaSalle	Nov. 15	9:15 a.m.		4.5	40.	9.7	74.9	At mouth
Illinois River	Starved Rock	" 15	9:30 a.m.		5.5	42.	8.6	68.1	Above Vermilion River
Vermilion River		" 15	9:45 a.m.		4.5	40.	12.5		
							12.7	97.1	At mouth
Illinois River	LaSalle	" 15	10 a.m.		5.5	42.	9.		
							8.9	70.7	Highway bridge, 1 mile below Vermilion River
" "	Peru	" 15	11 a.m.		6.	43.	8.8		
							9.	71.3	
" "	Spring Valley	" 15	11:30 a.m.		6.	43.	9.		
							8.9	71 3	
" "	Marquette	" 15	12:15 p.m.		6.	43.	9.1	72.8	
Hennepin Canal		" 15	12:45 p.m.		7.	45.	13.1		
							13.	106.	At lowest lock
Illinois River		" 15	1 p.m.		6.	43.	9.		
							8.9	71.3	At mouth of Hennepin Canal
" "	Hennepin	" 15	2:30 p.m.		6.5	44.	8.7		
							8.8	70.7	
" "		" 15	3 p.m.		6.5	44.	8.5		
							8.7	69.9	Twin Sister Island
Mud Lake		" 15	3:30 p.m.		5.5	42.	12.9	102.	1,000 ft. from Ill. River
Illinois River		" 15	3:30 p.m.		6.5	44.	8.8		
							8.6	70.8	Opposite Mud Lake
" "	Henry	" 15	4 p.m.		6.5	44.	8.9		
							9.1	73.3	Above dam

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen. p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River	Henry	Nov. 15	4 p.m.		7.	45.	9.1		
							9.2	64.7	Below dam
" "	"	" 16	10 a.m.		5.5	42.	8.7	69.	Opposite wharf
" " ...	Lacon	" 16	11:15 a.m.		5.5	42.	8.5	67.3	
" "	"	" 16	12 m.		6.5	44.	8.9	72.3	Opposite Babb's Slough
" "	Chillicothe.....	" 16	1:15 p.m.		6.5	44.	8.9		
							8.6	70.9	
" " ...	Peoria	" 16	1:30 p.m.		6.5	44.	9.2		
							9.1	74.	North end of Peoria Lake
Peoria Lake. ...	"	" 16	1:30 p.m.		6.5	44.	9.2	74.8	Partridge Island. west side
" "	"	" 16	1:45 p.m.		6.5	44.	9.7		
							9.2	75.5	Partridge Island, middle
" "	"	" 16	2 p.m.		6.5	44.	10.2	82.9	Partridge Island, east side
" "	"	" 16	2:30 p.m.		6.5	44.	9.8		
							9.6	78.9	Opposite Spring Bay
" "	"	" 16	3 p.m.		7.	45.	9.9	81.1	Below Horsor Slough, west side
" "	"	" 16	3 p.m.		7.	45.	9.5	77.9	Below Horsor Slough, mid-stream
" "	"	" 16	3 p.m.		7.	45.	10.8	88.6	Below Horsor Slough, east side
" "	"	" 16	3:30 p.m.		7.	45.	9.7		
							9.9	80.3	Opposite Peoria Heights
" "	Averyville.	" 16	3:45 p.m.		6.	43.	9.9	79.3	West side
" "	"	" 16	3:45 p.m.		6.5	44.	10.4		
							10.1	83.	Midstream
" "	"	" 16	3:45 p.m.		6.	43.	11.	88.1	East side
Illinois River....	Peoria	" 16	4 p.m.		6.	43.	10.6	84.1	At Liberty street, near shore

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Illinois River ..	Peoria	Nov. 16	4 p.m.		6.	43.	10.3	82.5	At Libertystreet, midstream
" " ...	"	" 17	8:45 a.m.		6.	43.	9.3		
							9.8	76.	Below distilleries
" "	Pekin	" 17	9:30 a.m.		6.	43.	9.6		
							9.8	77.7	
" "	"	" 17	10 a.m.		5.5	42.	9.7		
							9.6	76.	Below distilleries
" " ...		" 17	10:15		5.5	42.	9.7		
							9.8	76.6	Opposite Mackinaw River
" " ...	Kingston Mines .	" 17	10:30		5.5	42.	10.		
							9.8	78.5	
" "	Copperas Creek.	" 17	11:30		5.5	42.	10.1		
							10.	79.	Above dam
" " ...	" " ..	" 17	11:30		5.8	42.6	10.1	80.9	Below dam
" "	Liverpool.....	" 17	12:30		5.8	42.6	9.6		
							9.9	77.7	
Spoon River....		" 17	4 p.m.		4.5	40.	12.		
							11.9	92.3	At mouth
Illinois River...	Havana	" 17	4 p.m.		6.	43.	9.8		
							9.6	77.6	
" "		" 18	9:45 a.m.		5.	41.	10.1		
							9.8	77.3	Above Grand Island
" " ...		" 18	11 a.m.		5.3	41.6	10.1	79.9	Below Grand Island
" " ...	Sharp's Landing.	" 18	11:30		5.3	41.6	10.		
							9.9	78.4	
" " ...	Browning.....	" 18	12:30		5.5	42.	10.4	82.5	
" " ...	Beardstown	" 18	2 p.m.		6.	43.	10.2		
							10.	80.9	

TABLE OF DISSOLVED OXYGEN AND CARBON DIOXIDE, ILLINOIS RIVER AND RELATED WATERS, 1911 AND 1912 — *Continued*

Water	Location	Date	Hour	Depth of sample	Water Temp. C.	Water Temp. F.	Dissolved oxygen, p.p.m.	Dis. oxygen % sat'n.	Remarks
Crooked Creek...		Nov. 18	2:45 p.m.		5.	41.	10.4	81.3	At mouth
Illinois River		" 18	3 p.m.		5.8	42.6	10.7		
							10.5	84.8	Opposite Crooked Creek
" "	LaGrange	" 18	3:30 p.m.		6.	43.	9.8		
							10.1	79.4	Above dam
" "	"	" 18	3:45 p.m.		6.	43.	10.		
							10.3	81.8	Below dam
" "	Meredosia	" 19	7:15 a.m.		5.	41.	10.8		
							10.7	83.5	
" "	Naples	" 19	7:45 a.m.		5.	41.	10.9		
							11.	85.2	
" "	Valley City.....	" 19	8:30 a.m.		5.5	42.	10.8		
							10.6	84.7	
" "	Florence	" 19	9 a.m.		5.5	42.	10.7		
							10.5	84.1	
" "	Bedford	" 19	9:45 a.m.		5.5	42.	10.9	86.2	
" "	Pearl	" 19	10:30		5.8	42.6	11.5	92.	
" "	Kampsville	" 19	1 p.m.		6.	43.	11.1		
							11.2	88.9	Above dam
" "	"	" 19	1:15 p.m.		6.	43.	10.8	86.5	Below dam
" "		" 19	2 p.m.		6.	43.	10.9		
							10.6	85.7	Head of Diamond Island
" "	Hardin.....	" 19	2:20 p.m.		7.	45.	11.3		
							11.4	92.7	
" "		" 19	3:10 p.m.		6.8	44.6	10.9		
							11.5	91.8	Above Twelve Mile Island
" "		" 19	4:30 p.m.		6.5	44.	10.8		
							10.7	87.	At mouth
Mississippi R....	Grafton...	" 19	4:45 p.m.		6.5	44.	13.4		
							13.8	112.	West side
" "	"	" 19	4:50 p.m.		6.	43.	14.4		
							14.1	114.	Midstream
" "	"	" 19	5 p.m.		6.5	44.	11.		
							10.9	88.2	East side

EXPLANATION OF PLATES

Plate LXV

Upper Illinois River and principal tributaries.

Plate LXVI

Fig. 1. Des Plaines River and Sanitary Canal at Lockport
Fig. 2. Illinois River at Marseilles.

ERRATA

Page 497, line 9 from bottom, for *neglible* read *negligible,* and in footnote, for *Austalt* read *Anstalt.*

Page 498, line 4 from bottom, for *Lockport* read *Chillicothe.*

Page 500, line 13 from bottom, after *up* insert *in.*

Page 501, line 2 from bottom, for *dissolving* read *dissolved.*

Page 504, line 23, for *gryina* read *gyrina.*

Page 506, line 11, for *vernata* read *ternata.*

Page 507, line 3 from bottom, for *Mazon* read *wagon.*

Page 513, line 19, for *Nepa* read *Zaitha.*

Page 525, line 22, and page 536, lines 21 and 24, for Ekmann read Ekman.

Page 532, line 1, for *Ancyclus* read *Ancylus.*

Page 551, line 7, for *00* read *512.*

Plate LXXXV, for *7* read *7c.*

Plate LXXVII

View of Flag Lake, 1910.

Plate LXXVIII

Permanent overflow of Illinois River bottoms near Havana.

Plate LXXIX

Characteristic views from the middle course of the Illinois.

TABLE OF DISSOLVED OXYG

911 AND 1912 — *Continued*

Water	Loca	Remarks
Crooked Creek...		h
Illinois River		Crooked Creek
" "	LaGrange	am
" "	"	ım
" "	Meredosia	
" "	Naples ..	
" "	Valley Ci	
" "	Florence	
" "	Bedford .	
" "	Pearl	
" "	Kampsvil	
" "	"	ım
" "		ım
" "	Hardin...	Diamond Island
" "		
" "		welve Mile Island
Mississippi R....	Grafton..	h
" "	" ..	le
" "	" ..	.m
		e

EXPLANATION OF PLATES

Plate LXV

Upper Illinois River and principal tributaries.

Plate LXVI

Fig. 1. Des Plaines River and Sanitary Canal at Lockport
Fig. 2. Illinois River at Marseilles.

Plate LXVII

Illinois River at Morris.

Plate LXVIII

Marseilles Dam, June 15, 1901. View from north end.

Plate LXIX

Marseilles Dam, July 22, 1906. View from south end.

Plate LXX

South bank of Illinois River, below Ottawa.

Plate LXXI

In Horse-shoe Cañon, near Ottawa.

Plate LXXII

Illinois River bluff, immediately above Starved Rock.

Plate LXXIII

The Valley of the Illinois, from Starved Rock.

Plate LXXIV

The Valley of the Illinois, from Prospect Heights, above Peoria.

Plate LXXV

Sketch of waters near Havana, 1911.

Plate LXXVI

The Illinois River and bottom-land lakes, from Havana, 1910.

Plate LXXVII

View of Flag Lake, 1910.

Plate LXXVIII

Permanent overflow of Illinois River bottoms near Havana.

Plate LXXIX

Characteristic views from the middle course of the Illinois.

PLATE LXXX

Fig. 1. Illinois River levels, Havana. Monthly means, 1897-98 and 1909-10.
Fig. 2. Dissolved oxygen, Kankakee, upper Illinois, and Des Plaines rivers. midsummer of 1911.

PLATE LXXXI

Fig. 1. Dissolved oxygen, Illinois River. November data.
Fig. 2. Dissolved oxygen, Illinois River. Winter and midsummer data.

PLATE LXXXII

Fig. 1. *Eristalis tenax*, after Miall.
Fig. 2*a*-2*e*. *Hyalella knickerbockeri*: 2*a*, entire animal; 2*b*, first cheliped; 2*c*, first uropod; 2*d*, second uropod; 2*e*, telson, (U. S. Geol. and Geogr. Surv. of the Territories, 1873.)
Fig. 3. Slime worms, *Tubifex*, after Kolkwitz.
Fig. 4. *Rotifer actinurus*, after Kolkwitz.
Fig. 5. *Colpidium colpoda*, after Kolkwitz.
Fig. 6. *Paramecium putrinum*, after Kolkwitz.

PLATE LXXXIII

Fig. 1. *Paramecium caudatum*, after Blochman.
Fig. 2. *Vorticella microstoma*, after Blochman.
Fig. 3. *Epistylis plicatilis*, after Blochman.
Fig. 4. *Carchesium lachmanni*, after Kent.
Fig. 5. *Anthophysa vegetans*, after Blochman.
Fig. 6. *Anthophysa vegetans*, after Kent.
Fig. 7. *Chlamydomonas monadina*, after Blochman.
Fig. 8. *Oikomonas termo*, after Blochman.
Fig. 9. *Bodo saltans*, after Kolkwitz.
Fig. 10. *Stigeoclonium tenue*, after Kirchner.

PLATE LXXXIV

Fig. 1. *Chætophora elegans*.
Fig. 2. *Microthamnion kützingianum*, after Kirchner.
Fig. 3. *Cladophora crispata*, after Kolkwitz.
Fig. 4. *Cladophora glomerata*, after Kolkwitz.
Fig. 5. *Schizomeris leibleinii*. Tufts College Studies, Vol. II.
Fig. 6. *Ulothrix zonata*.
Fig. 7*a*-7*e*. *Chlorella vulgaris*. Rev. Gen. Botanique, Tome XV.
Fig. 8. *Lyngbya versicolor*. Minn. Algæ, Vol. I.
Fig. 9. *Phormidium uncinatum*. Minn. Algæ, Vol. I.
Fig. 10. *Oscillatoria limosa*, after Kolkwitz.

PLATE LXXXV

Fig. 1. *Cyclotella kützingiana*, after Kirchner.
Fig. 2. *Fragilaria virescens*, after Kirchner.
Fig. 3. *Tabellaria flocculosa*, after Kolkwitz.
Fig. 4. *Tabellaria fenestrata*, after Kirchner.
Fig. 5. *Melosira varians*, after Kolkwitz.
Fig. 6*a*, 6*b*. *Sphærotilus natans*, after Kolkwitz.
Fig. 7*a*, 7*c*. *Cladothrix dichotoma*, after Kolkwitz.
Fig. 7*b*. *Cladothrix dichtoma*, after Kirchner.
Fig. 8. *Beggiatoa alba*, after Kolkwitz.

UPPER ILLINOIS RIVER AND
PRINCIPAL TRIBUTARIES
SCALE
0 5 10 20 30 40 miles
DUPAGE
CHICAGO
DUPAGE RIVER
DES PLAINES RIVER
CHI DRAINAGE CANAL
LOCKPORT
JOLIET
LASALLE
FOX RIVER
KENDALL
GRUNDY
MORRIS
WILL
DEPUE
LAKE
PERU
LA SALLE
OTTAWA
MARSEILLES
RIVER
HENNEPIN
VERMILION
RIVER
CHICAGO RIVER
KANKAKEE
RIVER
KANKAKEE
HENRY
ILLINOIS
CHILLICOTHE
PEORIA LAKE
PEORIA

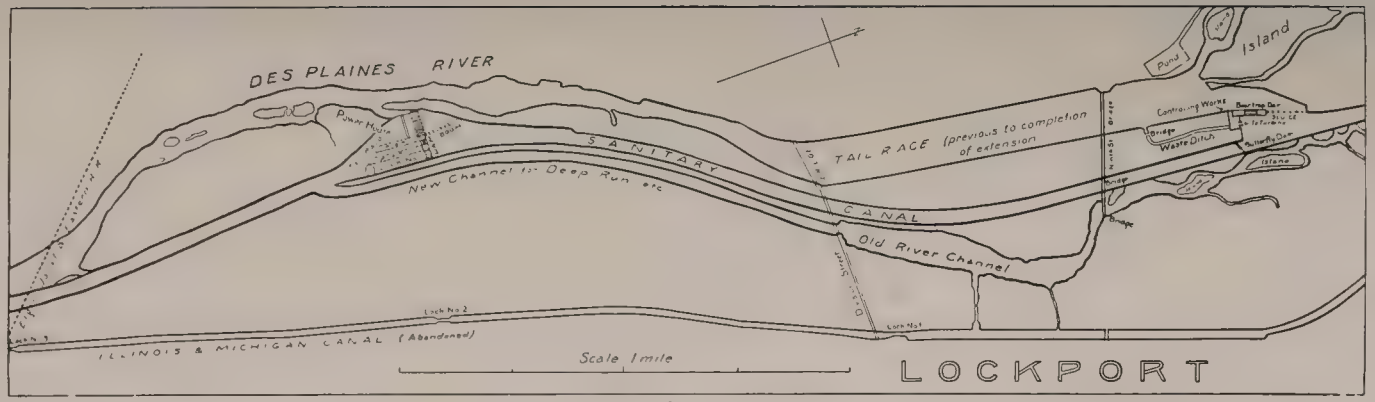

DES PLAINES RIVER
Power House
SANITARY
CANAL
New Channel to Deep Run etc
TAIL RACE (previous to completion of extension
Island
Pond
Waste Ditch
Old River Channel
Lock No 2
Lock No1
ILLINOIS & MICHIGAN CANAL (Abandoned)
Scale 1 mile
LOCKPORT

FIG. 1

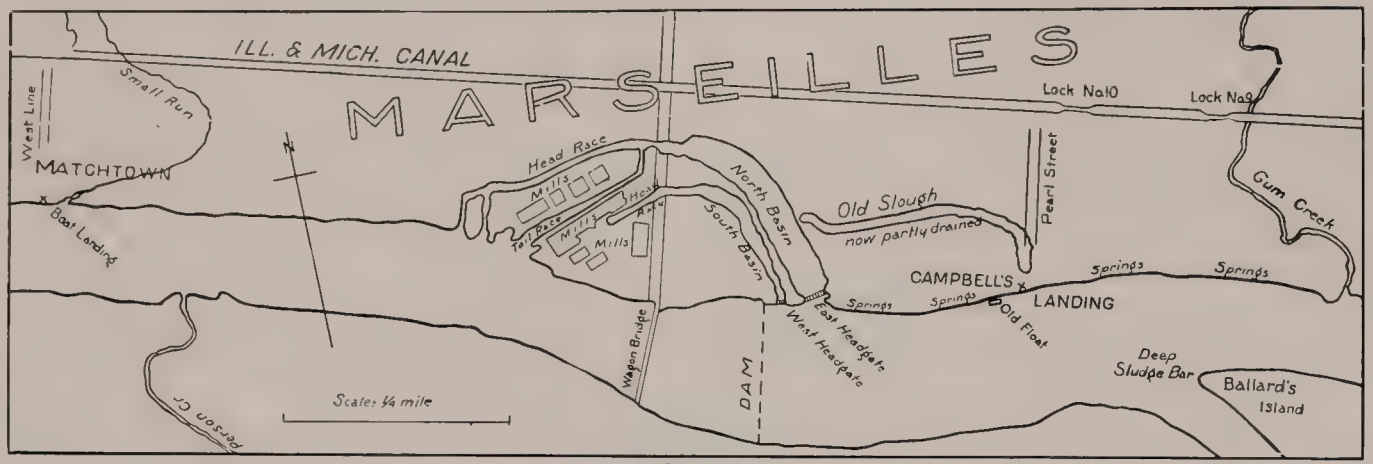

ILL. & MICH. CANAL
MARSEILLES
Lock No10
Lock No9
West Line
Small Run
MATCHTOWN
Boat Landing
Head Race
Mills
Tail Race
North Basin
South Basin
Old Slough
now partly drained
Pearl Street
Gum Creek
CAMPBELL'S LANDING
Springs
Old Float
East Headgate
West Headgate
Wagon Bridge
DAM
Deep Sludge Bar
Ballard's Island
Person Cr
Scales ¼ mile

FIG. 2

PLATE LXVII

MORRIS
Scale ¼ mile
COURT HOUSE SQUARE
ILLINOIS & MICHIGAN CANAL
Old Kindelspire's House
Kindelspire's Landing
Deep Sludge
Deep Bar
Kinney's Island
Mud Creek
Mazon Slough
Mazon River
Mazon R.
Slough
Nettle C.
Gridley Island
Wood Tannery
Bridge

PLATE LXVIII

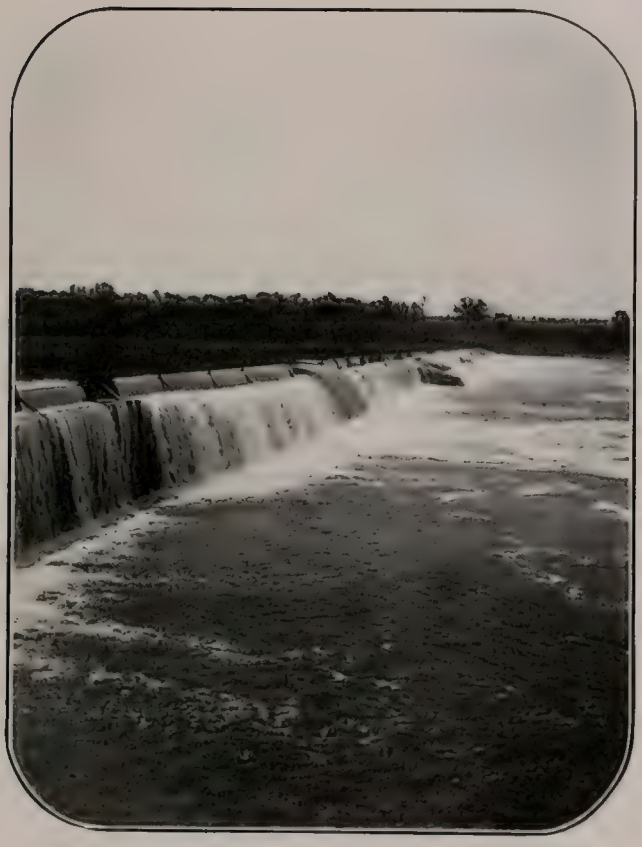


PLATE LXIX

PLATE LXX

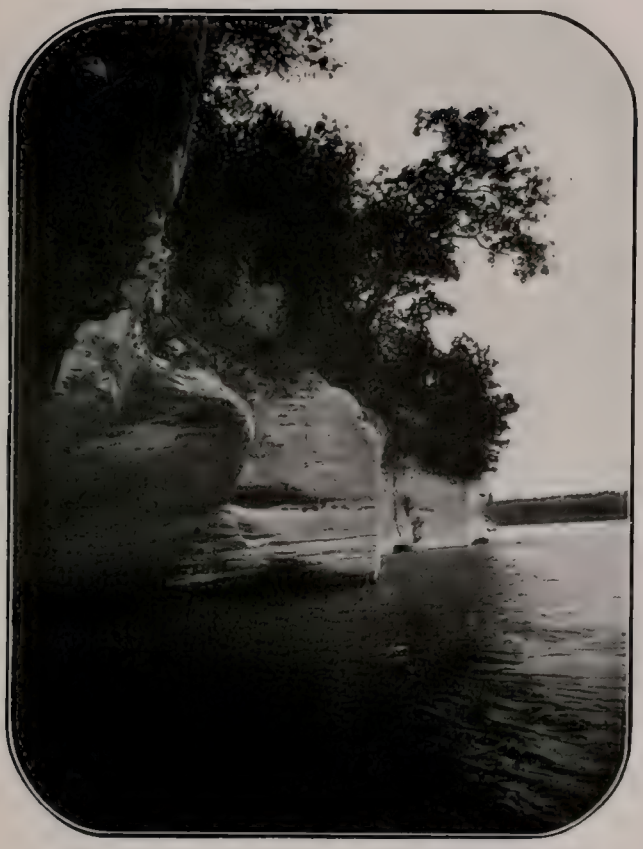


PLATE LXXI

PLATE LXXII

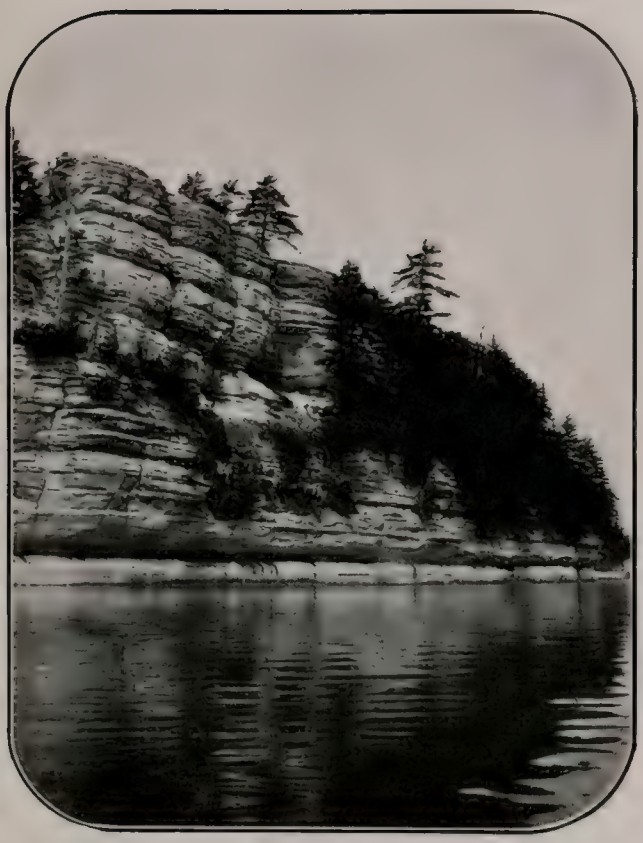
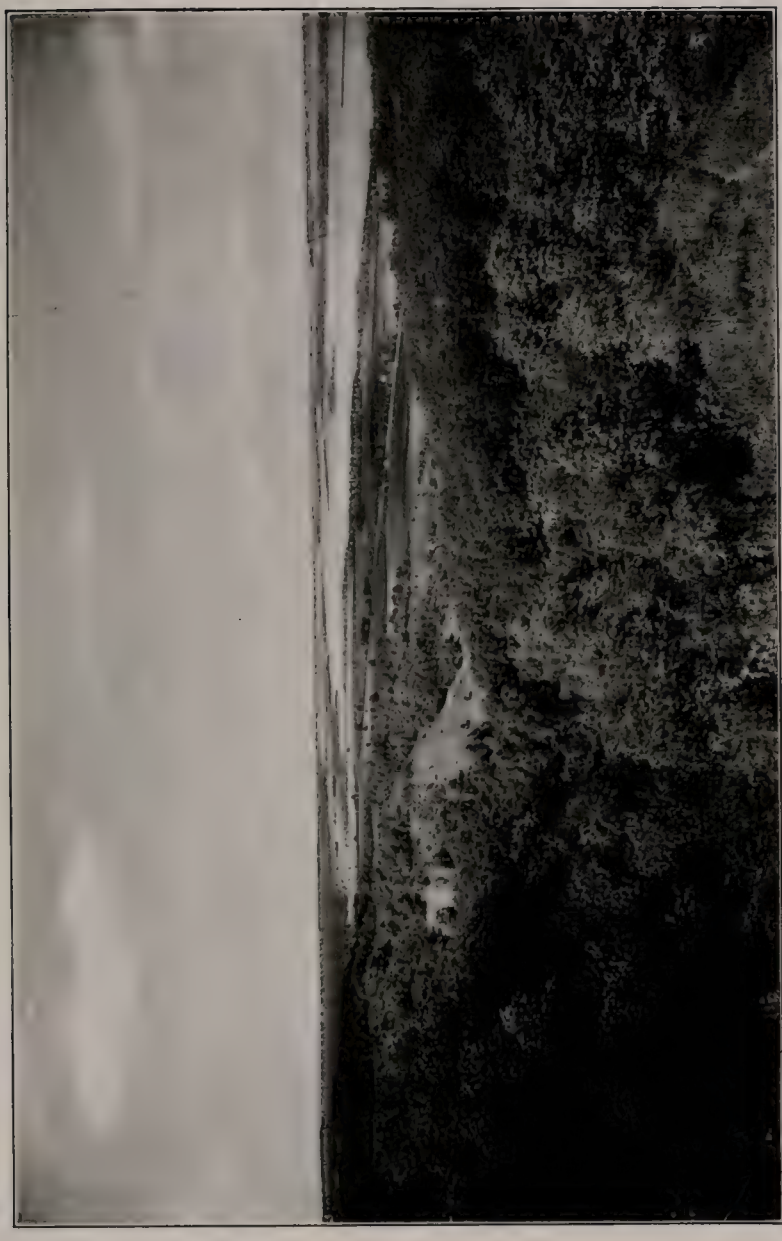


PLATE LXXIII

PLATE LXXIV



SKETCH OF WATERS NEAR HAVANA, 1911

PLATE LXXVI

PLATE LXXVII

PLATE LXXVIII

PLATE LXXIX

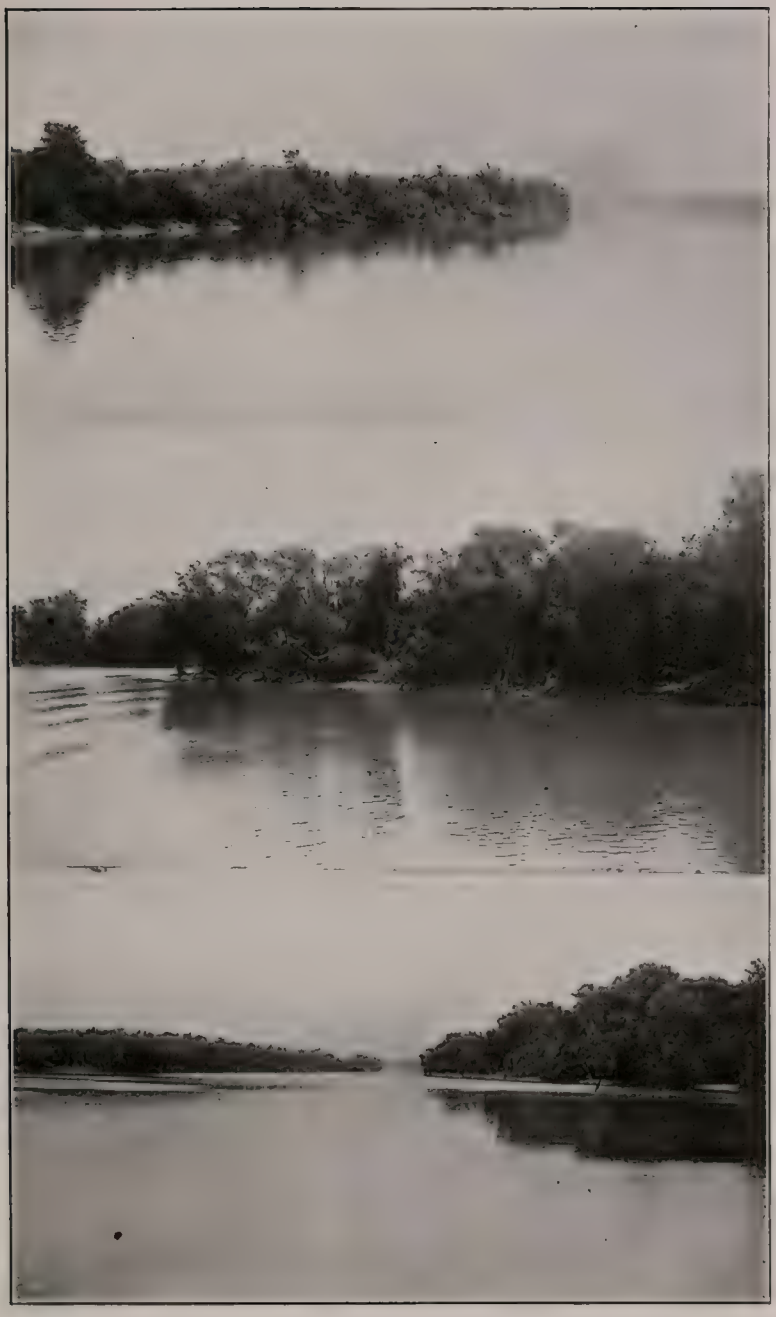


PLATE LXXX

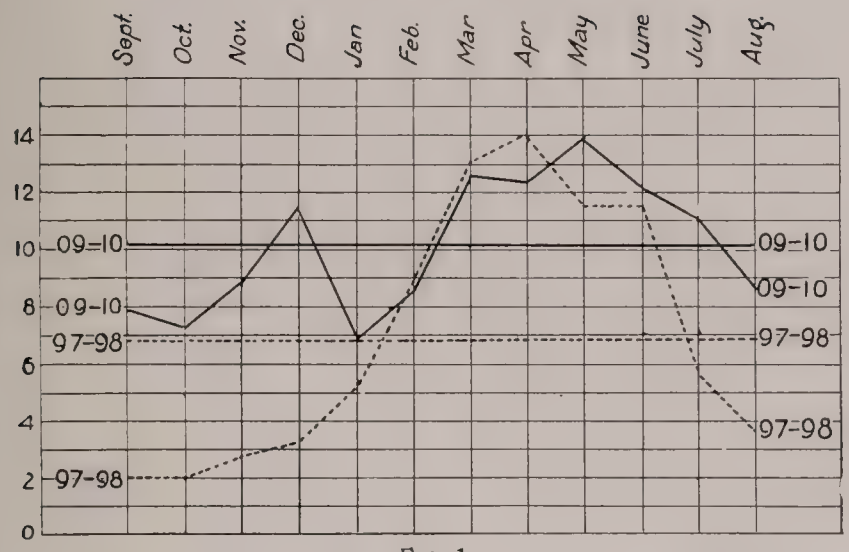


FIG. 1

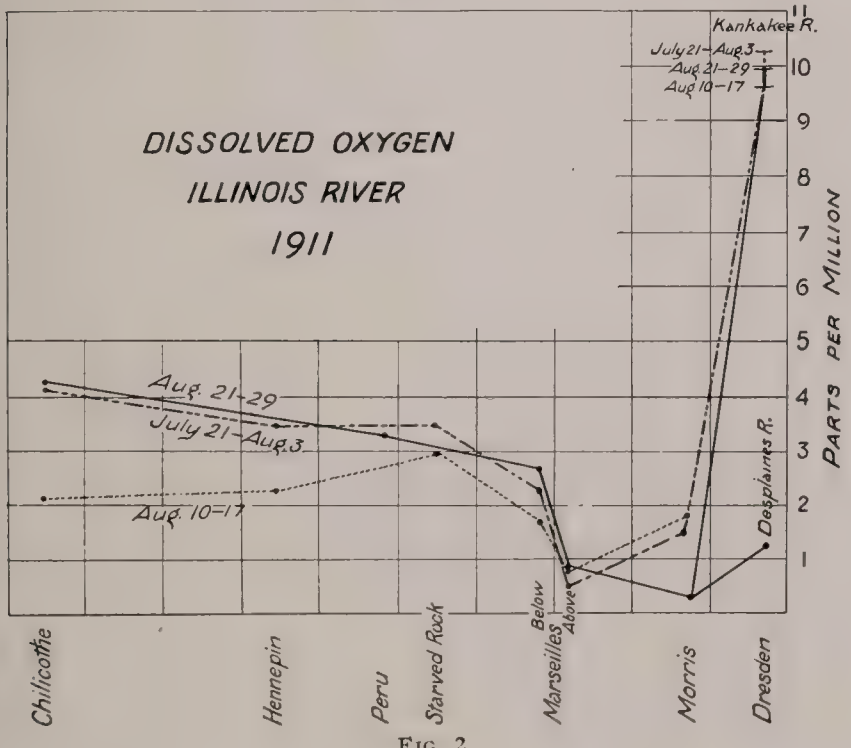


FIG. 2

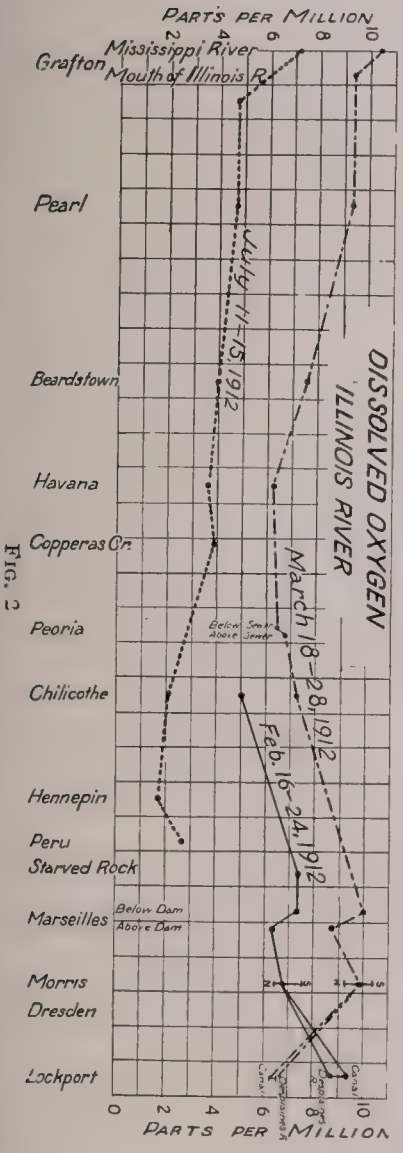

PARTS PER MILLION
DISSOLVED OXYGEN
ILLINOIS RIVER
Grafton
Mississippi River
Mouth of Illinois R.
Pearl
Beardstown
Havana
Copperas Cr.
Peoria
Below Sewers
Above "
Chilicothe
Hennepin
Peru
Starved Rock
Marseilles
Below Dam
Above Dam
Morris
Dresden
Lockport
July 11-15, 1912
March 18-28, 1912
Feb. 16-24, 1912
Des Plaines R.
Canal
0 2 4 6 8 10
PARTS PER MILLION

FIG. 2

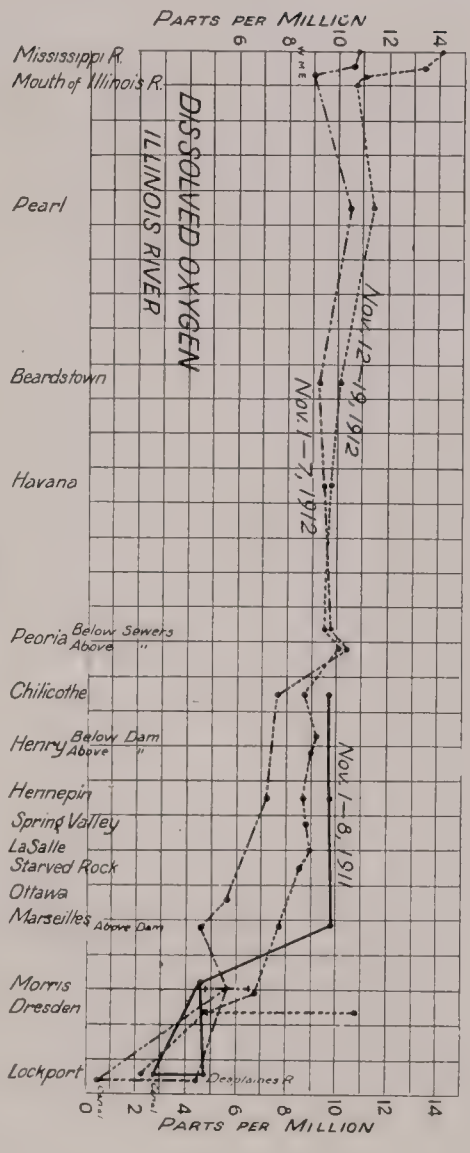
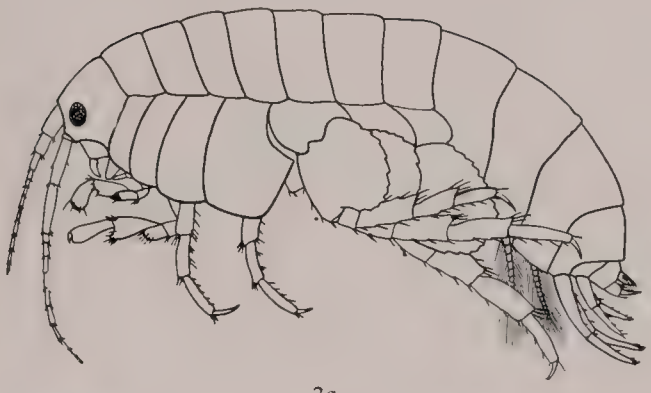

PARTS PER MILLION
DISSOLVED OXYGEN
ILLINOIS RIVER
Mississippi R.
Mouth of Illinois R.
Pearl
Beardstown
Havana
Peoria
Below Sewers
Above "
Chilicothe
Henry
Below Dam
Above "
Hennepin
Spring Valley
LaSalle
Starved Rock
Ottawa
Marseilles
Above Dam
Morris
Dresden
Lockport
Nov. 12-19, 1912
Nov. 1-7, 1912
Nov. 1-8, 1911
Des Plaines R.
Canal
0 2 4 6 8 10 12 14
PARTS PER MILLION

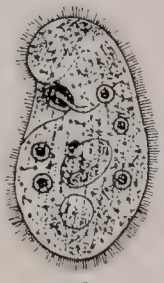
FIG. 1

Plate LXXXII

1



2a

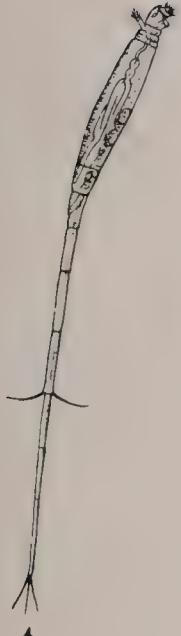


5

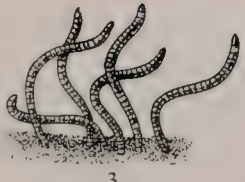
2b

2d

2e



4



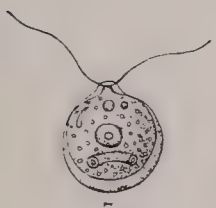
3

6

2c

Plate LXXXIII

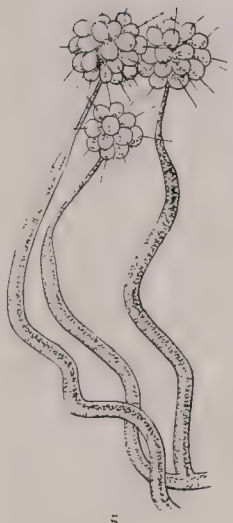
1



7

9

4

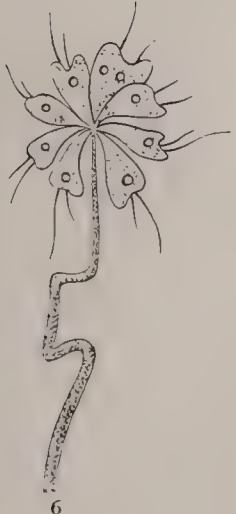


5

2

8

3



6

10

Plate LXXXIV

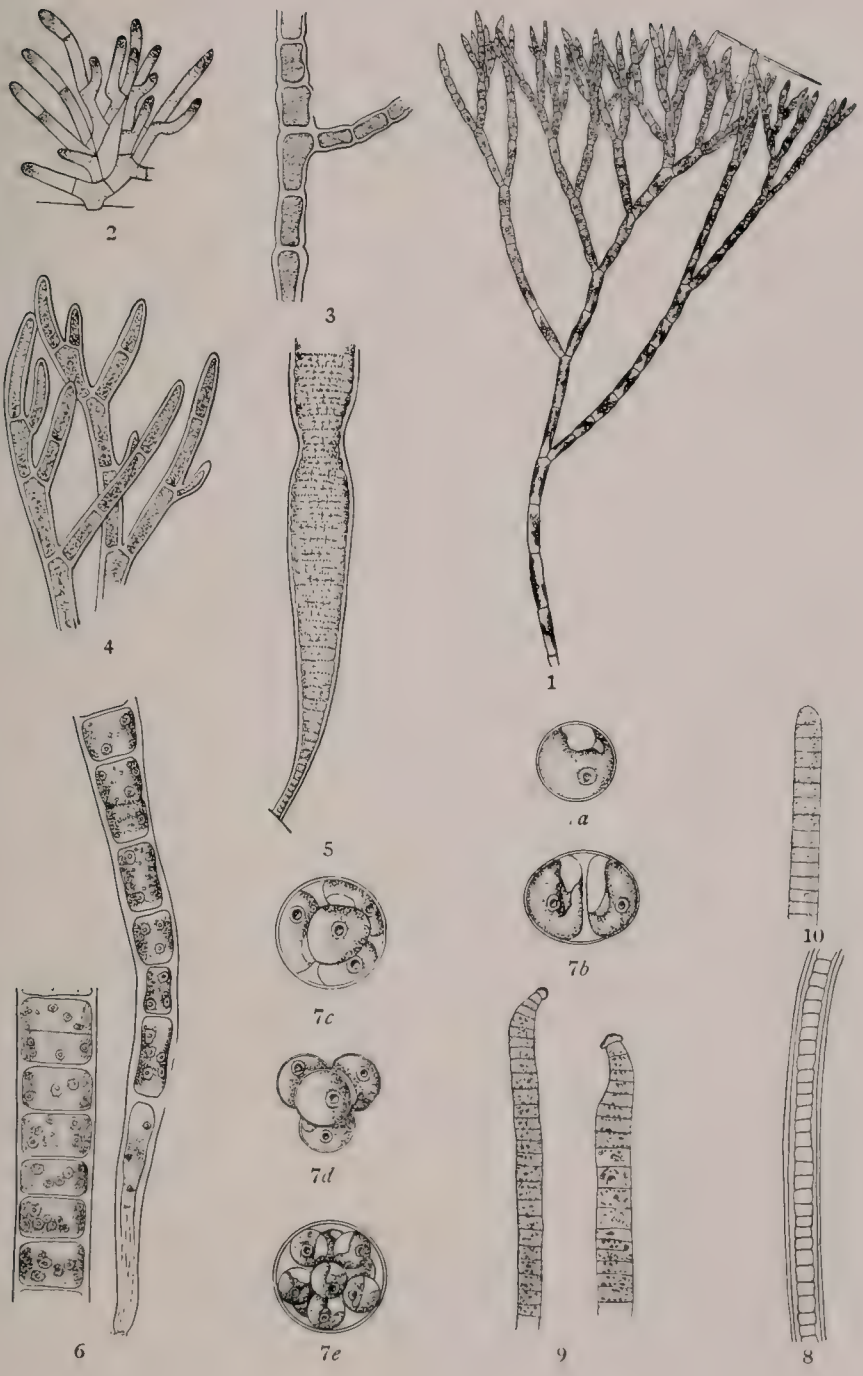
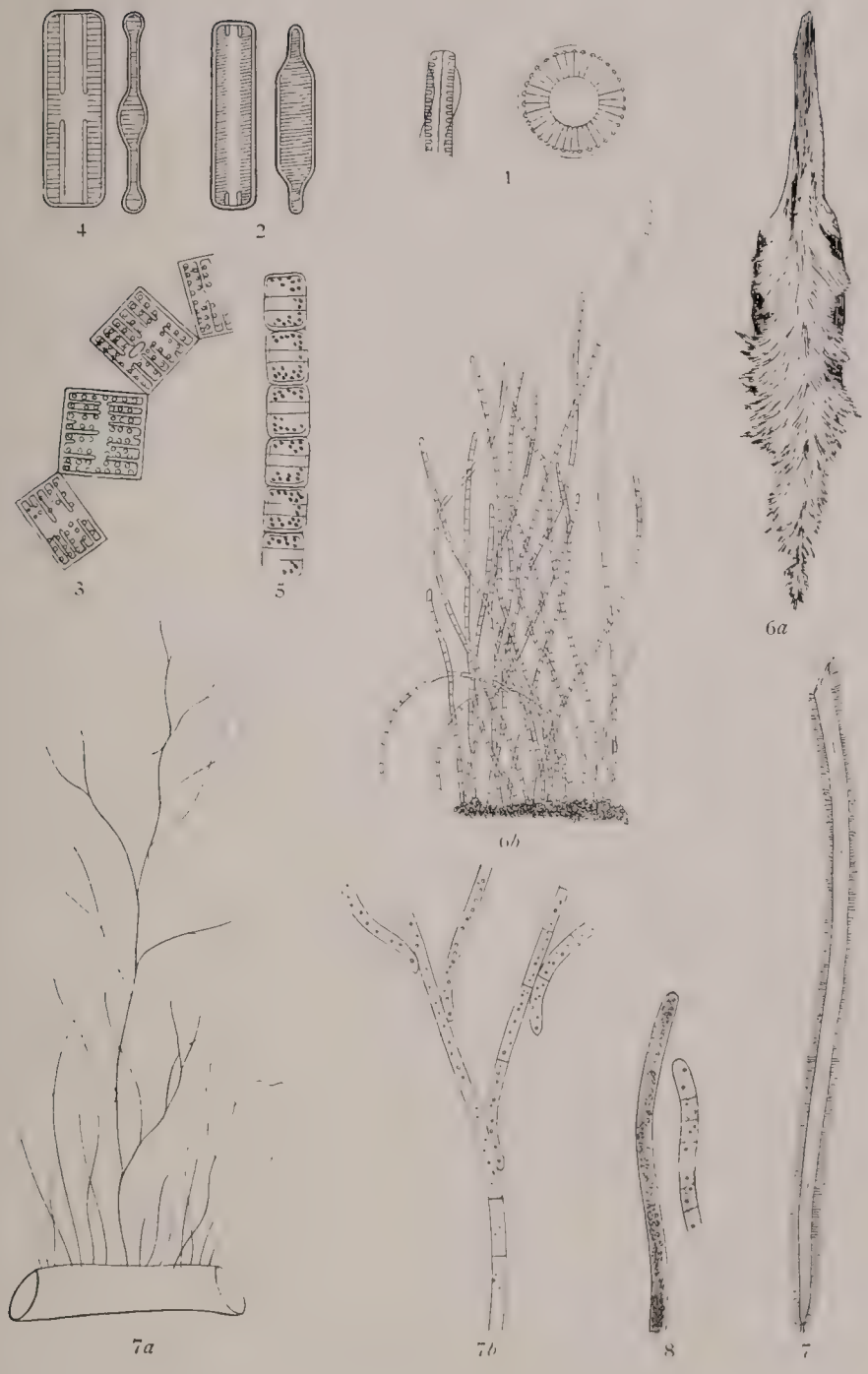


Plate LXXXV



BULLETIN

OF THE

ILLINOIS STATE LABORATORY

OF

NATURAL HISTORY

URBANA, ILLINOIS, U. S. A.

STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

VOL. IX. AUGUST, 1913 ARTICLE XI.

VEGETATION OF SKOKIE MARSH

BY

EARL E. SHERFF

ARTICLE XI.—*Vegetation of Skokie Marsh.* BY EARL E. SHERFF.

With the rapid encroachment of city and town upon the outlying districts about Chicago, and the consequent despoilation of the native flora, it has seemed to the writer advisable to undertake a careful study of a certain restricted area, while there is yet an opportunity, and to place these results on record. For several reasons, Skokie Marsh was deemed most worthy of study. During the past few years the so-called "North Shore" towns situated in the vicinity of the marsh have grown at a phenomenal rate. Much land but recently used in farming is now occupied by residences. Moreover, with further increases in population it appears certain that the whole marsh area will be thoroughly drained and, as a result, its floristic complexion be entirely changed. However, at the present time the flora is still essentially virgin in many places, and it is reasonably sure that the general survey here presented approximates closely to a truthful statement of natural conditions.

The general features of the flora and topography were studied mainly in the autumn of 1910 and the spring of 1911. From May to October, 1911, rather intensive taxonomic and ecological studies of the flora were pursued. Again, in 1912, frequent trips were made through various parts of the marsh to secure additional information as a check upon that already obtained.

Numerous specimens of plants were gathered from time to time. Of these a considerable number are now in my private herbarium; and many duplicates are in the Herbarium of the Field Museum (Chicago), the Missouri Botanical Garden Herbarium (St. Louis), Gray Herbarium of Harvard University (Cambridge), the United States National Herbarium (Washington), and the Herbarium of the Royal Botanic Garden (Edinburgh). The data secured, and here published for the first time in collected form, have already appeared in part in several other publications, which are cited in the appended list of literature. The map (Pl. LXXXVI, Fig. 1) is intended to portray merely the general location and extent of Skokie Marsh; hence certain of the roads running across the marsh are omitted. All the illustrations were made by the writer, resort being had to pen sketches where photographs were found impracticable.

Grateful acknowledgment is here made of my indebtedness, for many valuable suggestions and much helpful advice, to Dr. Henry C. Cowles and Mr. George D. Fuller, of the University of Chicago,

under whose joint supervision the main part of the investigation was pursued, and also to Dr. J. M. Greenman, of the Missouri Botanical Garden, for certain assistance in taxonomy.

General Features of Skokie Marsh

Skokie Marsh* is intimately associated with Skokie Stream—a small sluggish meandering stream beginning west of Waukegan, Ill., and extending southeast. Years ago this stream doubtless flowed on until it at last joined the East Branch of the North Branch of the Chicago River. Today, however, its identity as a stream is lost at a point west of Glencoe, Ill., where much of the water spreads itself over the marsh or enters some of the artificial drainage ditches. Figure 17, Plate XCIV, shows a more or less artificial basin at the south end of the marsh (west of Winnetka), in which water collects, flowing thence southward through a ditch. Southwest of Winnetka (west of Kenilworth and Wilmette), several broad drainage ditches may be seen. These receive much of their water, in circuitous ways, from Skokie Marsh and pass it on, all of it coming sooner or later into the North Branch of the Chicago River. One of these drainage ditches is shown in Figure 14, Plate XCII.

In recent years drainage and cultivation have been carried on to such an extent along the margins of the marsh that its areal limits can be defined only arbitrarily. As shown in the accompanying map (Pl. LXXXVI, Fig. 1) however, it is approximately 12 km. long, and at its southern end becomes 1.5 km. wide. For the naturalist, access to the marsh may be had at all times by means of the several roads running east and west directly across it. The scenery along certain of these roads (Pl. XCIII, Fig. 15) is particularly pleasing. During spring and autumn, the ditches running along either side of the roads are usually filled with water. In some of these the water is deep enough to permit the passage of a small boat. In the spring of 1912, when the marsh was in many places under water, a boat (Pl. XCIII, Fig. 16) was found very convenient for penetrating to the interior.

In early postglacial times, the marsh was an embayment (Atwood and Goldthwait, '08, p. 58), which later disappeared and gave place to a system of drainage. At present the surface soil almost throughout the marsh consists of a black muck or partially decayed peat, 1 m. or less in thickness. Underneath is a subsoil of glacial clay.

*For many additional data and photographs of Skokie Marsh, see Baker ('10), who has given also an account of its zoological aspects, with special reference to the molluscan fauna.

General Features of the Marsh Vegetation

Upon analysis, the vegetation at Skokie Marsh is found to consist of three rather pronounced formations.* Along the course taken by Skokie Stream, the plants constitute distinctly a reed swamp formation (Pl. LXXXVII, Fig. 2). Extending along on either side of the reed swamp is a broad level expanse, intermediate between reed swamp and meadow. This may be designated swamp meadow (Pl. LXXXVII, Fig. 3; Pl. XCIV, Fig. 18; Pl. XCV, Fig. 19). At the outer edges of the swamp meadow, in narrow areas that have not been too much disturbed by cultivation, true meadow is commonly present. At certain places, however, there is an abrupt transition from swamp meadow, or even from reed swamp, to forest. Such a case is shown admirably in Plate XCV, Fig. 20, which pictures a small piece of forest containing *Quercus rubra, Q. macrocarpa, Q. alba, Juglans nigra,* etc., separated from a branch of the reed swamp by a distance of only about 15 m.

In the reed swamp the plants belong to five easily recognized associations. Where the stream is deepest (as in Pl. LXXXVII, Fig. 2), aquatic or amphibious species, such as *Myriophyllum humile,*† *M. heterophyllum, Ranunculus delphinifolius,* and *Potamogeton (zosterifolius?)* are common near the center. In the shallower parts, the species are supplemented or replaced by *Polygonum Muhlenbergii, P. hydropiperoides, Veronica Anagallis-aquatica, Radicula aquatica, Sium cicutaefolium, Sparganium eurycarpum, Glyceria septentrionalis, Alisma Plantago-aquatica, Rumex verticillatus, Callitriche heterophylla,* and *C. palustris.* As *Polygonum hydropiperoides* and *Sium cicutaefolium* are among the most abundant stream plants and appear to be dominant, we may classify the plants growing in the stream or upon its bed, except along the margins, as the *Sium-Polygonum* association; or, using Schouw's method of nomenclature (Schouw, '22, pp. 148-150), we shall call this the *Sio-polygonetum* On either side of the Sio-polygonetum a narrow or sometimes broad girdle‡ of *Nymphaea advena* and *Castalia odorata* occurs in many

*The words "formation" and "association" are used throughout this paper in the sense accepted by Warming ('09, pp. 140, 144).

†All plant names given in this paper conform, unless otherwise noted, with the nomenclature of Gray's Manual (see Robinson and Fernald, '08).

‡The word "girdle" is here equivalent to the "zones" of many recent authors, and conforms with the recent proposal of Flahault and Schröter ('10), except that it is here used for "bands" that are not "concentric." Professor Schröter kindly informs me by letter that this use of their word is perfectly justifiable, and further says, "we should have made provision for such a use."

places along the stream. Usually these species are accompanied by species characteristic of the Sio-polygonetum; but the soil and light conditions present in the girdles of *Nymphaea* and *Castalia* are peculiar to them and justify their treatment as a separate association, the *Nymphaeetum*. Landward from the Nymphaeetum are found dense and either intermixed or almost pure growths of *Typha latifolia, Sparganium eurycarpum, Scirpus fluviatilis,* and *S. validus*. Scattered to a varying extent among these species are *Sagittaria latifolia* and *Sium cicutaefolium*. Here and there are a few isolated patches of *Dulichium arundinaceum,* of *Decodon verticillatus,* and of certain other species. This association will be referred to as the *Scirpo-typhetum*. Again, in certain parts of the reed swamp, at stations slightly less hydrophytic, *Phragmites communis* is prominent. It forms exceedingly compact, nearly pure colonies that may reasonably be treated as an association, the *Phragmitetum*. Finally, we must mention the many large but somewhat scattered patches of *Iris versicolor* and *Acorus Calamus,* occurring in the outer parts of the reed swamp and often extending into the swamp meadow formation. These constitute an association of a very definite stamp, the *Irido-acoretum*. A general comparison of the reed swamp associations shows that in the Sio-polygonetum and Nymphaeetum, where hydrophytism is greatest, the dominant plants are dicotyledonous. In fact, of the 15 species found to any considerable extent in these two associations, the 10 most abundant (*Sium cicutaefolium, Polygonum hydropiperoides, P. Muhlenbergii, Nymphaea advena, Castalia odorata, Rumex verticillatus, Veronica Anagallis-aquatica, Myriophyllum humile,* Callitriche palustris,* and *C. heterophylla*) are dicotyledons.† In the other three associations the most abundant species are chiefly monocotyledons.

The swamp meadow differs from the reed swamp in being more uniform, owing to greater parallelism between the water-table and the soil surface, and does not admit of logical subdivision into associations. The plants are principally such grasses as *Calamagrostis canadensis, Glyceria nervata, Phalaris arundinacea, Poa triflora, Sphenopholis pallens,* and *Agrostis perennans*. These are frequently interspersed with *Carex lupuliformis, C. vesicaria monile, C. riparia, Scirpus atrovirens, S. Eriophorum,* etc. The swamp meadow is used by farmers of the district for the production of marsh hay, and many of them customarily burn over the areas in the late autumn. Most of the shrubs and young trees are killed in this way, and so forest

*But see Nos. 136 and 137 in Annotated List.

†See Henslow ('11), however, regarding the supposed monocotyledonous nature of *Nymphaea* and *Castalia*.

development is hindered. Trees occur only in small groups, consisting chiefly of *Salix* (*S. fragilis, S. nigra,* and other species), *Fraxinus nigra, F. americana, Populus tremuloides,* and *Ulmus americana.* Frequently associated with these are such shrubs as *Cornus stolonifera, Cephalanthus occidentalis,* and *Sambucus canadensis.*

Throughout the reed swamp and swamp meadow are many species which, though very abundant, share only to a small extent in giving to the several associations their distinctive appearance. Thus, *Ludvigia palustris, Proserpinaca palustris, Penthorum sedoides,* and *Stenophyllus capillaris* are low in habit and obscured by taller plants in the shade of which they may thrive. Again, *Aster Tradescanti, Boltonia asteroides, Lobelia cardinalis, Teucrium occidentale,* and *Scutellaria galericulata,* while extremely common, are nevertheless conspicuous only during the latter part of the summer. The names of such species are here reserved, so far as possible, for the annotated list of species, at the end of this paper.

The meadow formation, as already stated, is narrow and more or less interrupted. The soil surface slopes mildly upward, away from that of the swamp meadow. The vegetation is much diversified at different places and from month to month during the vegetative season. *Poa pratensis* and *Agrostis alba* are the dominant grasses, but *Danthonia spicata* and *Agropyron caninum* are frequent. Scattered among the grasses are *Carex stipata, C. vulpinoidea, C. scoparia,* and *Eleocharis palustris.* In some parts of the meadow *Viola cucullata, V. papilionacea, Senecio aureus,* and *S. Balsamitae* are conspicuous in May and June, while later such species as *Lilium canadense* and *Rudbeckia hirta* are the most noticeable.

The stretches of forest present in many places at the edge of the marsh, while not usually considered as belonging to the marsh, are of interest because of the light that they throw upon the successional development of vegetation with the passing away of marsh conditions. Along the east side of the marsh, the ground surface slopes gently upward toward a rather high morainic ridge that roughly parallels the marsh; and as one proceeds toward this ridge, he leaves behind him such woody species as *Cornus stolonifera, C. Amomum, Cephalanthus occidentalis,* and *Salix longifolia,* and passes in turn thickets composed of *Sambucus canadensis, Populus tremuloides* and taller species of *Salix,* forest composed largely of *Quercus bicolor, Q. rubra, Fraxinus nigra, F. americana,* and *Ulmus americana,* finally reaching forest composed of *Quercus rubra* and such upland species as *Q. alba, Q. coccinea,* and *Carya ovata.*

Livingston, in his well-known studies of transpiration, found that, in a general way, the measure of transpiration in plants was fairly indicative of their respective environmental conditions. The transpiration rate for most plants being roughly proportionate to the rate of evaporation of water from a partially open receptacle, he introduced the porous-cup atmometer for measuring the evaporation rate of water. Four of these atmometers* were set out May 21, 1911, at different stations indicated on the map: an instrument at station 1, near the edge of Skokie Stream; one at station 2, in the outer part of the reed swamp; one at station 3, in the outer part of the swamp meadow; and one at station 4, in a stretch of forest east of the marsh. Instrument No. 1 was in the center of a dense growth of *Typha latifolia*. As the summer advanced, plants of *Scutellaria galericulata* and *Teucrium occidentale* grew up in the shelter of *Typha*. No. 2 was surrounded by *Iris versicolor, Sium cicutaefolium,* and a few plants of *Typha*. No. 3 was in a dense growth of *Calamagrostis canadensis,* and No. 4 in a small area of pastured forest, composed chiefly of *Quercus bicolor* and *Fraxinus americana,* but with a moderate proportion of *F. nigra*. The unglazed part of each porous-cup extended from about 22 cm. to about 28 cm. above the ground, giving a mean height of 25 cm. Readings were taken weekly, up to and including October 15, 1911. After correction according to the method outlined by Livingston, they were plotted graphically,† appearing as shown in Plate LXXXVIII, Fig. 4. The ordinates represent the number of cubic centimeters of water lost per day by a standard atmometer, while the abscissæ represent the intervals between the weekly readings.

A study of this figure (4, Pl. LXXXVIII) shows the periods of maximum and minimum evaporation to have been fairly harmonious at the four stations. And, again, the evaporation rate for the center of the reed swamp (Fig. 4, *a*), where hydrophytism is greatest, was usually lowest; in the swamp meadow (Fig. 4, *c*), it was somewhat higher; in the outer part of the reed swamp (Fig. 4, *b*), still higher; and in the *Quercus bicolor-Fraxinus americana* or swamp white oak-white ash forest (Fig. 4, *d*), it was highest of all. These differences become perhaps even more evident if we compare the following aver-

*None of the atmometers used were provided with a rain-excluding device, such as is recommended by Livingston ('14).

†A summarized account of these results first appeared in the *Botanical Gazette* (Sherff, '12), and later a more complete account, substantiallly as presented here, was published in the *Plant World* (Sherff, '13).

age daily evaporation amounts for the several stations for the entire period of 147 days: *a*, 3 cc.; *c*, 4.27 cc.; *b*, 4.5 cc.; and *d*, 7.91 cc. Or, taking the rate for *d* as 100%, then the rate for *a* was 38%; for *c*, 54%; and for *b*, 57%.* Expressed in general terms, the evaporation rates were inversely proportionate to the hydrophytism of the station. This is due chiefly to the greater amount of moisture in the air where the station is hydrophytic; and again, the greater amount of atmospheric moisture was due, in many places, not merely to the greater sources of supply (soil moisture or surface water) but to the more difficult means of escape (because of the tall rank vegetation evoked by hydrophytism). It will be noted that the average rate in the outer part of the reed swamp (*b*) slightly exceeded that in the swamp meadow (*c*). This may be explained easily, however, by the fact that in the swamp meadow the vegetation remained more dense and compact in late summer than in the outer part of the reed swamp, thus retarding evaporation.

Transeau ('08) has obtained in a mesophytic forest on Long Island, N. Y., an average daily evaporation rate of 8.5 cm. This was based upon readings taken during a period of less than one month. More recently, Fuller ('11) has obtained for typical mesophytic forest, based upon readings extending over 155 days, the average daily rate of 8.1 cc. While we are not justified by the data at hand in attempting final comparisons, yet, so far as they go, these data indicate that evaporation is slightly less rapid in the swamp white oak - white ash forest than in climax mesophytic forest. If this indication is sustained by further study, as it undoubtedly will be, it will coincide quite closely with the fact that in the normal development of mesophytic forest from hydrophytic formations *Quercus bicolor, Fraxinus americana, F. nigra,* etc., are antecedent to trees of the climax mesophytic type (*Fagus grandifolia, Acer saccharum,* etc.). By way of comparison, it is interesting to note here the very recent paper of M'Nutt and Fuller ('12), in which the oak-hickory forest association is maintained (because of its intermediate evaporation rate) "midway between the black oak dune association and the

*In interpreting these data, however, allowance must be made for the fact that in different associations the percentage of species which start out each year in the delicate and hence more critical seedling stage, varies. For young seedlings, dependent as they are upon their own photosynthetic activity for food, growth up to about 25 cm. (the height at which these comparative readings were taken) is accompanied undoubtedly by much more risk than is the growth of young shoots from old, well-established perennial rhizomes, bulbs, tubers, etc. Hence the evaporation rate for an entire association can not show with precision the extent to which each species, as such, is influenced during its most critical stages, viz., the first seasonal growth of its aerial shoots.

climax beech-maple forest, the position already assigned to it by Cowles and others in the forest succession of Indiana and Illinois."

In the autumn of 1911, a study of evaporation at different levels above the soil surface was made. Beginning September 3, weekly readings were taken with four atmometers arranged at different heights in a dense growth of *Phragmites communis,* and with three atmometers added to the one already at station I, among *Typha.* The last readings were taken on October 22. After correction to correspond with the readings of a standard atmometer cup, the data were plotted graphically. Among *Phragmites* (Pl. LXXXVIII, Fig. 5) the average daily evaporation for the 7 weeks, at 0 cm. (the soil surface), was 2.5 cc.; at 25 cm., 4 cc.; at 107 cm., 5.3 cc.; at 198 cm., in the uppermost atmospheric stratum among the *Phragmites* plants, 7.5 cc., or just three times as great as at the soil surface. Among *Typha* (Pl. LXXXVIII, Fig. 6)*, the average daily evaporation for the 7 weeks, at 0 cm., was .64 cc.; at 25 cm., 1.5 cc.; at 107 cm., 2.7 cc.; at 175 cm., in the uppermost stratum, 6.4 cc.—or just ten times as great as at the soil surface. These differences in the rates among *Typha* were strongly accentuated because the readings were taken in autumn, when many of the *Typha* leaves had started to wither and bend over, thus giving greater exposure in the upper strata and greater shelter in the lower. Then, too, numerous plants of *Scutellaria galericulata, Teucrium occidentale, Polygonum Muhlenbergii,* etc., absent among *Phragmites,* were present among *Typha* and acted as a further check to evaporation in the lower strata (in which, to a very great extent, they vegetated).

The data plotted in Figures 5 and 6, Plate LXXXVIII, corroborate very emphatically those of Yapp ('09), who found that during a total of about 15 days, the evaporation rate just above (*not,* as at Skokie Marsh, *in the upper strata of*) tall "sedge vegetation" was over fifteen times as great as it was at 12.5 cm. above the soil surface. They conform likewise with the more recent results of Dachnowski ('11), who obtained during about five days, at a height of 150 cm. in an American bog, an evaporation rate twice as great as at a height of 7.5 cm.; also with those of Fuller ('12) who obtained, during six months at a height of 2 m. in climax mesophytic forest, an evaporation rate 2.34 times as great as at a depth of 4 m. below the forest floor, in a ravine. Obviously, we must conclude,

*Because of the faulty working of the atmometer at 0 cm., the results for the first two and the last weeks are not plotted, and the average here given (.64 cc.) is for the remaining four weeks. Enough certain data were obtained however for the other three weeks to show that the total average would have been even less than .64 cc.

with Yapp, that plants may grow in proximity to each other and yet, if vegetating in different strata above the soil surface, be subject to widely different growth conditions. Thus, for example, *Riccia natans* and *Typha latifolia,* which may be found together in great quantity but vegetate mostly in different atmospheric strata, live under evaporation conditions differing much more than do those under which *Teucrium occidentale* (of the reed swamp) and *Aster salicifolius* (of the swamp white oak-white ash forest), plants of similar height and growth form, live.

The depth of the water-table in the reed swamp and the swamp meadow was observed each week from May 21 to October 22, 1911. The water in Skokie Stream was about 1 m. deep in May, after which it gradually declined until in July, when the stream bed was in most places fairly dry. In August the water began to rise again, and by October had reached an average depth of about 1.1 m. In the rest of the reed swamp and in the swamp meadow the water-table during May was coincident with or above the soil surface; thereafter it sank, until in early September the maximum depth of 1 m. in the reed swamp and 1.75 m. in the swamp meadow was reached; and then, rising rapidly, it reached the surface again by the middle of October. During 1912, water was much more abundant throughout the marsh. Seldom could the reed-swamp be traversed without the use of boots, even in midsummer. According to farmers in the vicinity of Glencoe, Skokie Stream has sometimes in the past risen until a depth of about 3 m. was reached, when the entire marsh was of course deeply submerged. Various attempts have been made to classify the constituent species of a formation with relation to the optimum water-table depth for each species. But where the water-table varies greatly in depth from month to month and from year to year, data must be secured through many years if they are to show more than merely the relative degrees of hydrophytism to which plants in different places are subject.

Litmus tests each week, from May 21 to October 22, 1911, showed the water in Skokie Stream to be either neutral or slightly alkaline. Similar tests showed the soil water in the outer parts of the reed swamp and in the swamp meadow to be usually neutral or slightly alkaline, except that for a few days in August acid was present, although the amount was almost negligible.

Subterranean Organs and their Interrelationships

A study of the subterranean organs of the reed swamp plants showed that in many cases their depth is roughly proportionate to

the depth of the water-table. Yapp ('08) arrived at a similar conclusion concerning the plants at Wicken Fen. And since the depth of the water-table may influence the depth of the subterranean organs, the latter in turn may be a potent factor in the success or failure of various species. Thus, for example, the rhizomes of *Polygonum Muhlenbergii,* where this species occurs in the Sio-polygonetum are usually at or near the surface of the stream bed. As King ('97, p. 240) and others have pointed out, saturated soil like that of the stream bed does not admit oxygen freely; and so in the Sio-polygonetum, the rhizomes of *Polygonum* and their roots appear advantageously placed. But in the Scirpo-typhetum (Pl. LXXXIX, Fig. 7), where the surface soil is occupied by an extremely dense mat composed of the rhizomes of *Typha, Sparganium,* and *Scirpus,* the rhizomes of *Polygonum* average about 10 cm. in depth; hence in the Scirpo-typhetum, although the rhizomes of *Polygonum* are lower, evidently in response to the greater average depth of the water-table, they have the additional advantage of being able to travel with less interference from the other rhizome systems.

An examination of *Typha, Sparganium, Scirpus fluviatilis,* and *S. validus* shows these species to be very similar in growth-form and hence capable of keen competition. Where any one of these species becomes more abundant in the Scirpo-typhetum, the others become less so. Because of the thick, strong rhizomes, the subterranean competition is to some extent mechanical; but it is probably to a much greater extent, as Clements ('05, pp. 285–289) maintains, physiological (or "physical"), especially in the case of the roots proper. The opposition that any or all of these species can offer to the intrusion of other species makes their hold upon the soil very effective. With *Sagittaria* (Pl. LXXXIX, Fig. 7), however, the case is different. Its growth-form favors a less compact arrangement of the individual plants, as its rhizomes can not produce a thick mat. Obviously, as the plants of *Sagittaria* are developing vegetatively, other species, such as *Typha, Sparganium,* and *Scirpus,* may easily invade and occupy the soil with their densely matting rhizomes. Subsequently the rhizomes of *Sagittaria,* if they are to establish new plants at proper distances away from the parent plant, must either plough their way through the surface mat of rhizomes or travel underneath it. They usually do the latter. As a rule, several rhizomes start growth from each plant in early summer in a downward direction; at a depth of 10–15 cm. they assume a horizontal direction for some distance; and then grow upward again, with a tuberous, propagative thickening near the distal end, and finally resemble somewhat a shal-

low, inverted arch.* Thus, interference from surface rhizomes and roots is to a great extent avoided. In this case, then, while it is not certain that the inverted arch of the *Sagittaria* rhizome is a direct adaptation to this particular struggle, it is certain that it is here of the greatest value, however induced originally.

Pieters ('01) found among the plants of western Lake Erie that even where *Sagittaria latifolia* was most abundant, *Sparganium* (and *Zizania*) had secured a foothold. On the other hand, throughout all the broad "zones" of *Sparganium, Scirpus validus* ("*S. lacustris*"), and *S. fluviatilis* that he describes, he says *Sagittaria latifolia* was common. Thus, in these cases, *Sagittaria* was found able to associate successfully with *Sparganium* and other species having a *Sparganium* growth-form, even where these species formed dense "zones". A study of the subterranean organs of *Sagittaria, Sparganium* (or *Typha* or *Scirpus*), and *Polygonum* shows that because of differences in direction or in depth they conflict but little. Again, because of differences in growth-form, their aerial parts do not conflict seriously. Thus a given area can usually support a greater mass of vegetation if these three growth-forms be present in fair mixture than if only one be present. Spalding ('09) has described the mutual relationships of *Cereus giganteus* and *Parkinsonia microphylla,* two desert species which thrive together because the occupation of different depths by their root systems enables them "to utilize to the utmost the scanty rainfall." Woodhead ('06) found *Holcus, Pteris,* and *Scilla* forming a noncombative "society or sub-association." For a group of plants mutually competitive, Woodhead uses the term "competitive association." Recently Wilson ('11) likewise speaks of a "complementary association" or "society." But the use of the words "association" and "society" in this connection is unfortunate. These words have been used already by Cowles ('01) and others (see Warming '09, p. 144) to denote a primary subdivision of a formation. As will be seen later (and in fact as Woodhead's interchangeable use of "sub-association" and "association" might imply), not all complementary or competitive groups are coextensive with a true association. We shall here substitute the word community, which is of less restricted application. Thus *Sagittaria* and *Polygonum,* where occurring in the Scirpo-typhetum with either *Typha* or *Scirpus fluviatilis* or *S. validus,* constitute a complementary community; but *Sparganium, Typha, Scirpus fluviatilis,* and *S. validus,* where they occur intermixed, form a competitive community.

*For illustrations of the similar rhizomes of *Sagittaria sagittifolia* see Glück ('05, pl. 6 and figs. 35, 39).

Species that are plainly complementary in one association may be less so in another. Thus, *Polygonum Muhlenbergii* and *Sparganium* are complementary in the Scirpo-typhetum; but in the Sio-polygonetum, where their rhizomes lie in common near or at the surface of the stream bed, they are "edaphically" (see Woodhead, '06) competitive, and hence complementary only in an aerial way. In this particular case, however, the frequently open appearance of the vegetation in the Sio-polygonetum indicates that the mutual biotic struggle of the two species is less keen than their separate struggles against somewhat adverse environmental conditions.

In the reed swamp certain mints become conspicuous during midsummer, particularly so in the Scirpo-typhetum, where they thrive in the shelter of *Typha* and other tall plants. *Teucrium occidentale* and *Scutellaria galericulata* are very common. They produce from their basal nodes numerous slender stolons that run out at different depths in the soil, and these stolons may produce new plants. These species tend to have their root systems 3–6 cm. lower in wet situations than in dry, although exceptions to this rule are not rare. But whether growing from plants in dry or from those in wet situations, the new stolons exhibit a remarkable power of changing their direction of growth, in response to numerous obstructions, and thus they may proceed further without serious results. Considering the strength and size of the rhizomes of *Typha, Sparganium,* and *Scirpus,* also the delicate nature of the stolons of *Teucrium* and *Scutellaria* and their capacity for altering growth-direction, it is probable that mechanical competition between such rhizomes as those of *Typha* and such stolons as those of *Teucrium* is practically absent. Again, the aerial parts of the *Typha* form vegetate chiefly in higher atmospheric strata than do those of the *Teucrium* form. Evaporation readings show that in higher strata evaporation is much greater; and while plants of relatively xerophytic structure (e. g., *Typha, Sparganium,* and *Scirpus*) are fitted to withstand acute drying conditions, plants with foliage of looser texture (e. g. *Teucrium* and *Scutellaria*) can vegetate better in lower strata, where the effect is that of greater humidity, the abundance of the latter plants among the former at Skokie Marsh tending to confirm this statement. Further, the persistence with which tall plants like *Typha* become dominant under favorable soil conditions shows that they are not, at least not noticeably, harmed by plants like *Teucrium.* If, finally, we allow for the great availability of nitrogenous foods in the soil and for the differences in food requirements, it becomes clear that the numerous

communities of *Typha* and *Teucrium, Typha* and *Scutellaria, Sparganium* and *Teucrium,* etc., are complementary.

The purity of the Phragmitetum has already been mentioned. Many species that flourish elsewhere in the reed swamp under a wide range of light, moisture, and other shelter conditions fail to thrive here. Only *Calamagrostis canadensis* gains noticeable entrance, and then imperfectly. The dead *Phragmites,* the growth of previous years, makes a considerable but loose covering near the soil, its decay not being facilitated as in the Scirpo-typhetum, where water is more abundant. This dead cover may perhaps act as a partial check upon the invasion of other species; but a study of the rhizomes of *Phragmites* (Pl. LXXXIX, Fig. 8) shows another fact which probably is more important. They do not occupy one particular level, but rather several different levels of soil. As a result, there is formed a dense mat of rhizomes and roots, about 2.5 dm. deep. Obviously, the subterranean organs of other species which might start growth here must compete with the extraordinarily large number of *Phragmites* roots and rhizomes. Where other factors are suited equally to *Phragmites* and to competing species, this biotic factor in the subaerial struggle ought usually to be decisive in favor of *Phragmites.*

No cases were found where *Phragmites* had regularly produced rhizomes (or stolons) upon the surface of the ground. Frequent instances were met with, however, in which the entire aerial shoot had fallen over upon wet, mostly nude soil and, having produced numerous roots, had elongated at a much more rapid rate than before.

The Nymphaeetum displays many complementary communities. The rhizomes of *Nymphaea advena* (Pl. XC, Fig. 9) are usually 5–10 cm. thick and lie mostly at a depth of 8–25 cm. below the soil surface. The rhizomes of *Castalia odorata,* while smaller, lie at a similar depth. Where the Nymphaeetum intergrades with the Scirpo-typhetum, as is commonly the case, the rhizomes of *Typha, Sparganium,* and *Scirpus validus* lie higher in the soil. In many places the soil surface itself is occupied by the stolons of *Ranunculus delphinifolius* and the creeping stems of *Polygonum hydropiperoides,* with a large, upright stem base of *Sium cicutaefolium* present here and there. In other places, *Ranunculus* is replaced by *Myriophyllum humile* or by young plants (growing chiefly from detached leaves) of *Radicula aquatica,* while *Polygonum* is replaced by *Veronica Anagallis-aquatica,* and *Sium* by *Rumex verticillatus.* And while it is true that *Nymphaea* and *Castalia,* or *Typha* and *Sparganium* and

Scirpus, or *Ranunculus* and *Myriophyllum* and *Radicula,* or *Polygonum* and *Veronica,* or *Sium* and *Rumex* are mutually competitive, yet a complete community (as shown, e. g., in Pl. XC, Fig. 9) is complementary; the basal parts chiefly because of different depths, and the upper parts chiefly because of different growth-forms.

An inspection of the Nymphaeetum shows that only where *Nymphaea* is nearly or quite absent does *Sagittaria latifolia* successfully invade from the Scirpo-typhetum. As is commonly known, the rhizomes of *Nymphaea* in many habitats are usually decayed to within a short distance of the growing apex. An investigation during August, 1911, showed that generally where the rhizomes of *Sagittaria* had penetrated these decayed parts, they themselves had started to decay.* Frequent cases were found where the decayed *Nymphaea* rhizomes lay nearer the surface and the *Sagittaria* rhizomes had proceeded underneath, unharmed. In many instances, however, where the stem-tubers had been mechanically impeded (by woody roots, etc.) in the encasing soil, they had decayed. And here, while the decay must have been due to some one or more physiological causes, yet these causes could not have operated had not mechanical impediments first retarded the stem-tubers for a sufficient length of time. As our knowledge of the interrelationships of subterranean organs progresses in the future, we shall probably find that often, in the case of certain species with large subterranean parts, there is offered or received mechanical resistance which is immediately decisive in competition because of the physiological processes that it promotes.

Speaking in a general way, while *Nymphaea* and *Sagittaria* thrive better in the Nymphaeetum and Scirpo-typhetum, respectively, yet along the line of tension between these two associations the injury done by the decayed *Nymphaea* rhizomes to the rhizomes of *Sagittaria* is a factor that appears to be decisively in favor of *Nymphaea.* The inverted rhizome arch of *Sagittaria,* useful in the Scirpo-typhetum, is here more often harmful.

In many parts of the Irido-acoretum, *Polygonum Muhlenbergii* and *Galium Claytoni* abound, and these form with *Acorus* a complementary community (Pl. XC, Fig. 10). The creeping stems of *Galium* root upon the soil surface, the rhizomes of *Acorus* lie just beneath, and those of *Polygonum* are deepest of all. The bushy shoot of *Galium* appears not to harm the slender, ensiform leaves of *Acorus,* and they in turn do little harm to it. In late summer, the

*Many litmus tests uniformly showed the decayed parts of the *Nymphaea* rhizomes to be strongly acid. Enough cultural experiments have not been performed, however, to determine whether the effect upon the *Sagittaria* rhizomes, as above noted, was due to acid or to other causes.

shoots of *Polygonum* rise above those of *Acorus* and *Galium* without apparent harm to either of them. And while *Polygonum* might increase in abundance if *Acorus* and *Galium* were entirely absent, still to a great extent the community, viewed as a whole, is complementary. Elsewhere in the Irido-acoretum the rhizomes of *Acorus* are replaced by those of *Iris;* and very often the rhizomes of *Galium* are replaced by those of *Ludvigia palustris, L. polycarpa, Proserpinaca palustris, Penthorum sedoides, Veronica scutellata,* or *Campanula aparinoides.*

The basal parts of the various swamp meadow species are usually more slender than those of the reed swamp species, and hence the texture of the surface mat of rhizomes, roots, etc., is finer. Then, too, reproduction by seeds becomes more common. *Polygonum Muhlenbergii* is present in the swamp meadow, and by means of its extensively creeping rhizomes, which lie rather low, it forms in some places large patches. Certain other perennials, e. g., *Asclepias incarnata* and *Sium cicutaefolium,* which root near the surface, may reproduce largely by seed or by new shoots arising from the old stem base of the preceding year. In the middle and latter parts of the summer, when the surface soil is no longer saturated with water, such annuals as *Panicum capillare, Echinochloa crusgalli, Eragrostis hypnoides, Stenophyllus capillaris, Polygonum Persicaria, Acnida* sp. (see Annotated List, No. 89), *Amaranthus paniculatus,* and *Erechtites hieracifolia* take possession of all exposed surface soil and become exceedingly abundant. Much of the surface soil that has been denuded by burning or by other causes is already occupied, however, by the rhizomes of perennials such as *Ludvigia palustris, L. polycarpa, Proserpinaca palustris,* etc. In these cases *Boltonia asteroides, Callitriche heterophylla,* and *C. palustris* are often abundant. Both species of *Callitriche,* however, die away in midsummer, being replaced by annuals. Figure 11, Plate XCI, shows such a community. *Callitriche,* maturing earliest, is "seasonally" (Woodhead '06) complementary with the other species. *Boltonia* roots lowest, while its aerial shoot grows much the highest; and since it is not harmed very much by *Proserpinaca, Ludvigia,* and *Penthorum,* while they derive, if anything, benefit from its shelter, *Boltonia* is complementary both aerially and subaerially. *Proserpinaca, Ludvigia,* and *Penthorum* are very similar throughout in growth form and they constitute mutually a competitive community; but, even though mutually competitive, they form with *Boltonia* and *Callitriche* a community that may properly be called complementary.

As has been stated already, the flora of the meadow is highly diversified. A very large number of definite interrelationships, similar to those detailed for the reed swamp and the swamp meadow, are found to exist, but lack of space precludes more than a brief description of a few examples. In the moist parts of the meadow, the soil at a depth of 3–12 cm. frequently contains the tuberous thickened roots of *Cicuta maculata* and *Oxypolis rigidior*, and also the tuber-bearing rhizomes of *Equisetum arvense*. In drier situations the bulbs of *Lilium canadense* occur at a similar depth (most often about 10 cm. deep). Higher in the soil may be found (Pl. XCI, Fig. 12) roots of such species as *Asclepias incarnata*, *Thalictrum revolutum*, and *Lathyrus palustris*, while the surface soil contains a mixture of the root systems of *Poa pratensis*, *Agrostis alba*, *Eleocharis palustris*, *Acalypha virginica*, etc. In the community shown in the figure just mentioned, *Equisetum* is edaphically complementary, but (considering only the aerial sterile shoots) aerially competitive with *Poa*, *Agrostis*, *Eleocharis*, and *Acalypha*. To a moderate extent, the plants rooting near or at the surface appear to be complementary with the plants rooting deeper.

Small, apparently open depressions are numerous in the moist parts of the meadow. These generally contain (Pl. XCII, Fig. 13) such plants as *Iris*, *Acorus*, *Viola conspersa*, *V. cucullata*, *V. papilionacea*, *Cardamine bulbosa*, and seedlings of *Lycopus americanus*. And while the rhizomes of *Cardamine* and *Lycopus* occur almost invariably just below those of the other species, and while the different species doubtless make different demands upon the soil, yet edaphic competition is undoubtedly sharp. Their rhizomes are mostly short and thick, lie just below or at the soil surface, and form a dense mat. Nevertheless, when one or more square feet of this mat were carefully removed and the soil in the interstices among the rhizomes was taken away, it was estimated that the interstices, as viewed from above, constituted from 35 to 60 per cent. of the total. Evidently, then, so far as mere room was concerned, several other species could have grown—in fact, did grow—in these interstices. But they were plants which rooted higher or lower; or, if at the same level, they were species not largely dependent upon rhizomes or stolons for multiplication. Thus, where *Iris versicolor* had reached a maximum of frequency, *Polygonum Muhlenbergii*, with a low fibrous root system, and *Galium Claytoni*, with a high root system, might live, but *Acorus Calamus*, with rhizomes similar to those of *Iris versicolor* and lying at a similar depth, and dependent largely on rhizomes for multiplication, was absent.

The almost complete absence, in these small areas, of stoloniferous or loosely spreading species makes it seem certain that there exists some mechanical competition in which species of compact and frequently cespitose habit or species capable of reproducing extensively from seed are successful. The extent, however, to which their success is achieved because of their growth-form or because of their superior adaptation to the particular complex of soil and moisture conditions in these small areas, is of course incapable of accurate estimation without further study. The idea of mechanical competition (*i. e.*, a struggle either among the various species because of the mutual bodily resistance of any or all of their growing parts, or of individual species because of the resistance offered by the soil's compactness to the locomotion of their subterranean organs) is opposed by Clements ('05, pp. 285-289); but Warming ('09, p. 324), in accounting for the usual absence of vegetative locomotion among perennial herbs of the meadow formation, seems inclined to accept this idea in part.

Summary and Conclusions

1. Atmometer readings at a uniform height of 25 cm., taken for a period of 147 days at four different stations, show that the evaporation rate is lowest in the center of the reed swamp and gradually increases as conditions approximating those of forest are reached.

2. The evaporation rate found to obtain in the swamp white oak - white ash forest, conforms with the commonly known fact that with successive increases in the mesophytism (attended with decreasing hydrophytism) of a forest, trees such as *Quercus bicolor, Fraxinus nigra,* and *F. americana* are antecedent to trees like *Fagus grandifolia* and *Acer saccharum.*

3. Atmometer readings, taken for seven weeks at four different levels among *Phragmites* plants and at five different levels among *Typha* plants, show that among marsh species of compact social growth evaporation is proportionate to the height above the soil. These results thus coincide with those of Yapp ('09).

4. Data accumulated at Skokie Marsh support the conclusion of Massart ('03) that it is a matter of importance to perennial plants that their hibernating organs occupy a definite level in the soil.

5. Certain observed cases of variation in this level (*Teucrium occidentale, Polygonum Muhlenbergii,* etc.), corresponding to changes in the water-level, indicate that with certain species, at least, the depth of the water-table is much the most potent controlling factor (cf. Yapp, '08).

6. Two or more species may live together in harmony because (1) their subterranean stems may lie at different depths; (2) their roots may thus be produced at different depths; (3) even where roots are produced at the same depth, they may make unlike demands upon the soil; (4) the aerial shoots may have unlike growth-forms; or (5) even where these growth-forms are similar, they may vegetate chiefly at different times of the year. According as one or more of these conditions control the floristic composition of a given community the community may be called complementary.

7. The root depth having been determined by various factors for the different species in a community, the specifically different root systems then function in a complementary or a competitive manner as the case may be. But even if the root systems be complementary, the community may be competitive because of marked competition among the aerial parts. Likewise, competitive root systems may render competitive a community otherwise complementary.

8. Through the ability of certain species to utilize different strata in the soil, the aerial portions of these plants are brought into a closer competition. And with closer competition, the chances in the past for further adaptation of similar aerial shoots to dissimilar growth conditions must have been greatly increased. Hence communities formerly complementary in a purely edaphic way, may have been largely instrumental in the evolution of completely complementary communities. In so far as they have been thus instrumental, the fact deserves great emphasis, especially when we consider the far-reaching changes in form and anatomical structure necessarily developed as a prerequisite to living in a completely complementary community.

Annotated List of Plant Species

As a matter of taxonomic interest to botanists in the future, it seems worth while to present here an annotated list of all the species of the *Pteridophyta* and *Spermatophyta* found growing to any extent in Skokie Marsh. Stray species (especially weeds), occasionally observed, have not been included in the list, except where evidence indicated that they were regular inhabitants. Also, many weeds which occur along the roads traversing the marsh and which do not properly belong to the marsh flora, are omitted. As the following list stands, then, it includes only the established species found in the reed swamp, swamp meadow, and meadow of Skokie Marsh proper.

Polypodiaceae

1. *Aspidium Thelypteris* (L.) Sw.
   Mostly in the swamp meadow and outer parts of the reed swamp; fairly frequent.
2. *Onoclea sensibilis* L.
   In the swamp meadow and reed swamp; rather rare.

Equisetaceae

3. *Equisetum arvense* L.
   In the meadow; frequent.

Typhaceae

4. *Typha latifolia* L.
   In the reed swamp; abundant.

Sparganiaceae

5. *Sparganium eurycarpum* Engelm.
   In the reed swamp; very abundant, in many places almost choking up the streams and ditches. In late summer, 1911, after the water in Skokie Stream had fairly well disappeared, great quantities of young aerial shoots were put forth by this species where it occurred upon the stream bed. When these shoots flowered and fruited, they manifested a striking appearance, in that they were yellowish green in color,—not dark green, as was the species elsewhere (cf. Harshberger, '04, p. 136).

Najadaceae

6. *Potamogeton* sp.
   Potamogeton material was found in 1911 in several of the deeper places in Skokie Stream from the county line (Braeside) road as far north as to Lake Forest. This was not in fruit, but appeared on careful comparison with herbarium specimens to be *P. zosterifolius.*

Alismaceae

7. *Sagittaria latifolia* Willd.
   Very common in the reed swamp and frequent in the swamp meadow. Occasionally, detached stem-tubers from this species were found being carried along slowly in Skokie Stream, indicating that *Sagittaria* may at times migrate considerable distances in a purely vegetative way.

8. *Alisma Plantago-aquatica* L.
In reed swamp; common. Confined mostly to the very wet places.

Gramineae

9. *Panicum capillare* L.
Along ditches, stream-banks, etc. Very common in late summer.

10. *Echinochloa crusgalli* (L.) Beauv.
Prominent in late summer in open or mown areas.

11. *Leersia oryzoides* (L.) Sw.
In reed swamp and swamp meadow; frequent.

12. *Phalaris arundinacea* L.
In the outer reed swamp, also in swamp meadow; abundant. Yapp, ('08, p. 67) has pointed out that the leaves of *Phragmites*, because of the slippery inner surface of their sheath, can easily turn about so as to stream with the wind. The same was found at Skokie Marsh to be true, though in a lesser degree, of *Phalaris arundinacea*.

13. *Phleum pratense* L.
In the meadow, where it was more or less frequent, probably because of its occasional cultivation in certain fields near the marsh.

14. *Alopecurus geniculatus* L.
In the swamp meadow and outer parts of the reed swamp, west of Glencoe; sparsely scattered.

15. *Agrostis alba* L.
Common in many parts of the meadow; occasional in the more open parts of the swamp meadow.

16. *Agrostis perennans* (Walt.) Tuckerm.
In meadow and swamp meadow; abundant, especially west of Glencoe.

17. *Calamagrostis canadensis* (Michx.) Beauv.
The dominant grass of the swamp meadow and frequent in the reed swamp; forms the bulk of the hay obtained in Skokie Marsh.

18. *Sphenopholis pallens* (Spreng.) Scribn.
In the swamp meadow; scattered in very small patches.

19. *Danthonia spicata* (L.) Beauv.
In dry parts of the meadow, west of Glencoe; found sparingly.

20. *Spartina Michauxiana* Hitchc.
Along ditches, in moist depressions, etc.; found only rarely.

21. *Phragmites communis* Trin.
In conspicuous dense patches in the reed swamp; abundant west and southwest of Glencoe.

22. *Eragrostis hypnoides* (Lam.) BSP.
Very common in the wet open places of the reed swamp; fairly frequent in the swamp meadow.

23. *E. Frankii* (Fisch., Mey. & Lall.) Steud.
In moist open places of the reed swamp; found sparingly.

24. *Poa compressa* L.
In the meadow; rare.

25. *P. triflora* Gilib.
Very common in the swamp meadow. West of Glencoe this grass forms a fair percentage of the marsh hay obtained each summer.

26. *P. pratensis* L.
In the meadow; abundant.

27. *Glyceria nervata* (Willd.) Trin.
In the swamp meadow; common, especially west of Glencoe. Often occurring in almost a pure growth.

28. *Glyceria septentrionalis* Hitchc.
Along Skokie Stream or upon the stream bed; frequent.

29. *Agropyron caninum* (L.) Beauv.
Found in only one part of the meadow, west of Glencoe.

30. *Hordeum jubatum* L.
Commonly with *Poa triflora* and *Agrostis perennans*, in the swamp meadow; frequent along the roadsides.

31. *Elymus virginicus* L.
Along ditches; occasional.

Cyperaceae

32. *Dulichium arundinaceum* (L.) Britton
Only one patch found, this in the reed swamp west of Braeside.

33. *Eleocharis obtusa* (Willd.) Schultes
In the swamp meadow and reed swamp; scattered mostly in open moist places.

34. *E. palustris* (L.) R. & S.
In grassy places of the meadow and swamp meadow; common. West of Winnetka this species was found growing in Skokie Stream, where it was much stouter and attained an average height of .6 to .7 m.—a fact conforming wtih the observations of others (cf. Gray's Manual, Robinson and Fernald, '08, p. 183).

35. *Stenophyllus capillaris* (L.) Britton
Everywhere in the reed swamp and swamp meadow; common.

36. *Scirpus validus* Vahl.
In very wet parts of the reed swamp; common.

37. *S. fluviatilis* (Torr.) Gray
In the center of the reed swamp, where it frequently fringes Skokie Stream in large patches.

38. *S. atrovirens* Muhl.
Scattered here and there, often abundantly, in outer parts of the reed swamp and swamp meadow.

39. *S. lineatus* Michx.
Found with the last species, but only rarely.

40. *S. cyperinus* (L.) Kunth.
In the swamp meadow; rare.

41. *S. Eriophorum* Michx.
In the outer reed swamp and in the swamp meadow; common.

42. *Carex scoparia* Schkuhr.
In the swamp meadow and moister parts of the meadow; common.

43. *C. cristata* Schwein.
Same range; common.

44. *C. vulpinoidea* Michx.
Same range; common.

45. *C. stipata* Muhl.
Same range; common.

46. *C. cruscorvi* Shuttlw.
Occurring in two small patches west of Glencoe, in wet soil. Mr. E. J. Hill informs me that many years ago he found a considerable quantity of this species there.

47. *C. aurea* Nutt.
In swamp meadow, west of Glencoe; found sparingly.

48. *C. lanuginosa* Michx.
In swamp meadow; in some places, covering considerable areas.

49. *C. riparia* W. Curtis
Mostly in the swamp meadow; abundant.

50. *C. lupuliformis* Sartwell
Observed west of Braeside, in the outer part of the reed swamp.

51. *C. lupulina* Muhl.
In the swamp meadow; seemingly rare.

52. *C. vesicaria* L., var. *monile* Tuckerm.
Mostly in the swamp meadow; fairly common.

NOTE.—Several other species of *Carex*, among them probably *C. granularis*, were found, but because of their immature condition or complete lack of flowers and fruit, positive determination could not be made.

Araceae

53. *Acorus Calamus* L.
In the reed swamp; common.

Lemnaceae

54. *Spirodela polyrhiza* (L.) Schleid.
Abundant in some places upon the surface of the water in Skokie Stream.

55. *Lemna trisulca* L.
In Skokie Stream west of Glencoe; found in 1911 and 1912, at only one place.

Juncaceae

56. *Juncus tenuis* Willd.
In the meadow; occasional.

57. *J. Dudleyi* Wiegand
Same range; occasional.

Liliaceae

58. *Lilium canadense* L.
In the meadow; common, especially west of Glencoe.

Iridaceae

59. *Iris versicolor* L.
In the reed swamp and swamp meadow; common.

Orchidaceae

60. *Habenaria leucophaea* (Nutt.) Gray
Observed in the meadow, west of Glencoe; only one small colony of plants found.

Salicaceae

61. *Salix nigra* Marsh.
Here and there in wet soil, mostly along the roads.

62. *S. amygdaloides* Anders.
The most abundant of the willow trees in Skokie Marsh; preferring the wet places.

63. *S. alba L.*, var. *vitellina* (L.) Koch
Occasional as a large tree in rows along ditches west of Glencoe and Winnetka, where it was evidently planted by man.

64. *S. longifolia* Muhl.
Frequently covering low wet depressions in the swamp meadow. Flowering in frequent cases until late autumn. (Pl. XCVI, Fig. 21.)

65. *S. cordata* Muhl.
In wet places; frequent.

66. *S. discolor* Muhl.
In wet places; common.

S. discolor var. *prinoides* (Pursh) Anders.
Several shrubs in the marsh, appearing as hybrids between *S. discolor* and *S. cordata*, are referred to this variety.

67. *S. petiolaris* J. E. Smith
In meadow and outer part of swamp meadow; occasional.

68. *S. humilis* Marsh.
In the meadow; found only sparingly.

69. *S. rostrata* Richards
West of Glencoe and Ravinia; rare.

NOTE.—Two or three other forms of *Salix* were found, which were not typical of any known species, but appeared to be hybrids between certain species enumerated above. In the absence of expert opinion concerning their status, separate treatment is here omitted. *Salix fragilis*, occurring in the swamp meadow along certain roads and apparently adventive recently, is likewise omitted in the list.

70. *Populus tremuloides* Michx.
In thickets, small patches of forest, etc.; frequent.

71. *P. grandidentata* Michx.
With the last, but rather rare.

72. *P. deltoides* Marsh.
Along ditches and roads; merely a few scattered trees.

Urticaceae

73. *Ulmus americana* L.
A few large trees here and there. (Pl. XCVI, Fig. 22.)

Polygonaceae

74. *Rumex britannica* L.
In the reed swamp; frequent.

75. *R. crispus* L.
Occurring sparingly in the meadow (but common along the roadsides).

76. *R. altissimus* Wood
In the swamp meadow; occasional.

77. *R. verticillatus* L.
Very abundant at many points in Skokie Stream; frequent in other parts of the reed swamp.

78. *Polygonum aviculare* L.
In the meadow, where principally along paths; occasional.

79. *P. lapathifolium* L.
In the swamp meadow; rather common.

80. *P. Muhlenbergii* (Meisn.) Wats.
Abundant in the reed swamp; frequent in the swamp meadow.

81. *P. pennsylvanicum* L.
In a few open, fairly dry areas of the reed swamp; not common.

82. *P. Hydropiper* L.
Mostly in the Irido-acoretum of the reed swamp; common, becoming very abundant at certain points.

83. *P. acre* HBK.
Occurring with *P. Hydropiper*, but less abundant.

84. *P. Persicaria* L.
Scattered, in open parts of the swamp meadow; frequent.

85. *P. hydropiperoides* Michx.
Confined mainly to Skokie Stream, in which, at some points (especially west of Braeside and Glencoe), it occurs in great abundance, to the almost complete exclusion of other species.

86. *P. sagittatum* L.
In the outer parts of the swamp meadow; rare.

87. *P. scandens* L.
Rare in the marsh proper; confined mostly to roadside thickets.

Chenopodiaceae

88. *Chenopodium album* L.
In open spots of the meadows; frequent.

Amaranthaceae

89. *Acnida* sp.
Very common along Skokie Stream and in more open spots of the swamp meadow. Material was originally determined according to the older manuals as *A. tamariscina* (Nutt.) Wood. Absence of pistillate plants among my specimens makes it impossible now to apply positively the more precise nomenclature of Gray's New Manual (see Robinson and Fernald, '08, p. 373); but the Skokie Marsh plants probably belong to *A. tuberculata* Moq. and its variety *subnuda* Wats.

90. *Amaranthus paniculatus* L.
In open, fairly dry spots of the swamp meadow. In 1912, this species was found only rarely, and it is probable that much of the material considered in 1911 as *A. paniculatus* was the upright form of *Acnida* sp.

Caryophyllaceae

91. *Arenaria latcriflora* L.
About thickets in the meadow and outer swamp meadow; somewhat frequent.

92. *Stellaria longifolia* Muhl.
Among the grasses and sedges of the swamp meadow; frequent.

93. *Cerastium nutans* Raf.
In a few open, moist, shady spots in the swamp meadow; rather rare.

94. *Nymphaea advena* Ait.
In the Nymphaeetum of the reed swamp; abundant and conspicuous.

95. *Castalia odorata* (Ait.) Woodville & Wood
With *Nymphaea advena,* to which it appears ecologically equivalent; common or even abundant.

Ranunculaceae

96. *Ranunculus delphinifolius* Torr.
Abundant in Skokie Stream; the seedlings frequent in open or sheltered moist depressions of the swamp meadow.

97. *R. sceleratus* L.
In meadow and swamp meadow; rare.

98. *R. Pennsylvanicus* L. f.
Here and there in the swamp meadow; somewhat rare.

99. *Thalictrum revolutum* DC.
In the meadow; frequent.

100. *Caltha palustris* L.
In the swamp meadow; rare.

Cruciferae

101. *Radicula palustris* (L.) Moench
In the swamp meadow; abundant.
Radicula palustris, var. *hispida* (Desv.) Robinson
Growing with the species proper, and abundant. Of the hundreds of specimens examined, none was found showing any intergradation with the species itself.

102. *R. aquatica* (Eat.) Robinson
Abundant in Skokie Stream, especially west of Glencoe. Appearing to renew itself chiefly by its detaching leaves, which take root and propagate new plants,—a habit already noted by other observers.

103. *Cardamine bulbosa* (Schreb.) BSP.
In the reed swamp, swamp meadow, and moist parts of the meadow; common.

104. *C. pennsylvanica* Muhl.
In the reed swamp and swamp meadow; common. Numerous seedlings develop in late summer and flower until late autumn.

Crassulaceae

105. *Penthorum sedoides* L.
In the reed swamp and swamp meadow; common.

Saxifragaceae

106. *Ribes floridum* L'Hér.
In thickets; somewhat frequent.

107. *R. nigrum* L.
In thickets; apparently rare.

Rosaceae

108. *Fragaria virginiana* Duchesne
In the outer meadow; fairly frequent.

109. *Potentilla monspeliensis* L.
In the meadow and open spots of the swamp meadow.

110. *P. palustris* (L.) Scop.
Growing with *Typha latifolia,* west of Braeside and Glencoe; only two small patches observed. Aerially, this species is strongly complementary with *Typha;* it utilizes the lower atmospheric strata, where it flourishes among the aerial shoots of *Typha.*

111. *P. canadensis* L.
In drier parts of the meadow; occasional.

112. *Geum virginianum* L.
In open places of the swamp meadow; rare.

113. *Rosa blanda* Ait.
In the meadow; frequent.
Doubtless one or two other species of *Rosa* are present, but the scanty material obtainable did not admit of certain determination.

Leguminosae

114. *Trifolium pratense* L.
In the meadow; occasional.

115. *T. repens* L.
In the meadow; common.

116. *Lathyrus palustris* L.
In the meadow; frequent.

Oxalidaceae

117. *Oxalis corniculata* L.
In the meadow and open, drier places of the swamp meadow; occasional.

Euphorbiaceae

118. *Acalypha virginica* L.
In the meadow and near various thickets; frequent.

Callitrichaceae

119. *Callitriche palustris* L.
Very common (as also the next following species) in the reed swamp and moister parts of the swamp meadow in early summer, when water is abundant.

120. *C. heterophylla* Pursh
With *C. palustris,* the two species often entering mutually into the composition of a compact mat, the whole appearing to the naked eye as a single species.

Balsaminaceae

121. *Impatiens biflora* Walt.
In moist, shady spots; occasional.

Rhamnaceae

122. *Rhamnus Frangula* L.
Occurring in a thicket, west of Glencoe. The finding of this species in an established condition at Skokie Marsh has already been recorded elsewhere (Sherff, '12). Heretofore it has been frequent in cultivation, but our manuals list no place farther west than Ontario for the western limit of its established range.

Vitaceae

123. *Vitis vulpina* L.
In various thickets of the marsh; frequent.

Hypericaceae

124. *Hypericum majus* (Gray) Britton
In open spots in the swamp meadow; frequent.

125. *H. canadense* L.
In similar situations; frequent.

Violaceae

126. *Viola cucullata* Ait.
In the moister parts of the meadow; common.

127. *V. papilionacea* Pursh
In similar situations; common. Much of the material slightly different from the typical form; but Professor Ezra Brainerd, to whom some living specimens from Skokie Marsh were sent a year ago for cultivation in his own garden, kindly informs me that he considers them to be *V. papilionacea.*

128. *V. conspersa* Reichenb.
In the meadow; frequent.

Lythraceae

129. *Decodon verticillatus* (L.) Ell.
In the reed swamp; found at one station west of Glencoe. Its tough roots were observed in several cases to have impeded very effectively the progress, through the soil, of the stem-tubers of *Sagittaria* and *Sparganium.*

Onagraceae

130. *Ludvigia polycarpa* Short & Peter
In the reed swamp and swamp meadow; common.

131. *L. palustris.* (L.) Ell.
In the reed swamp and swamp meadow; very abundant.

132. *Epilobium angustifolium* L.
In the outer part of the meadow, west of Glencoe; rare.

133. *Epilobium coloratum* Muhl.
In the swamp meadow; common. Appearing to pass by various intergradations into the next species.

134. *E. adenocaulon* Haussk.
With *E. coloratum;* common.

135. *Oenothera muricata* L., var. *canescens* (T. & G.) Robinson
In open places in the swamp meadow; occasional.

Haloragidaceae

136. *Myriophyllum heterophyllum* Michx.
In Skokie Stream; abundant in 1912.

137. *M. humile* (Raf.) Morong
In the Skokie Stream; very abundant in 1911, but rare in 1912, having been almost entirely replaced by the above species.

138. *Proserpinaca palustris* L.
In the reed swamp and swamp meadow; very abundant.

Umbelliferae

139. *Osmorhiza longistylis* (Torr.) DC.
About thickets; rare.

140. *Cicuta maculata* L.
In the swamp meadow and moist parts of the meadow; frequent.

141. *Sium cicutaefolium* Schrank
In the reed swamp and swamp meadow.

142. *Oxypolis rigidior* (L.) Coult. & Rose
About thickets; somewhat rare.

Cornaceae

143. *Cornus Amomum* Mill.
In wet thickets along the marsh border, ditches, depressions, etc.; frequent.

144. *C. stolonifera* Michx.
With *C. Amomum;* somewhat rare.

145. *C. paniculata* L'Hér.
With *C. Amomum;* fairly frequent.

Primulaceae

146. *Lysimachia thyrsiflora* L.
In the reed swamp; very rare.

147. *Steironema ciliatum* (L.) Raf.
In shaded places in the meadow; rare.

Oleaceae

148. *Fraxinus americana* L.
Here and there in the small "islands" of forest.

149. *Fraxinus nigra* Marsh.
With the last species, but in wetter soil.

Gentianaceae

150. *Gentiana Andrewsii* Griseb.
In moist grassy thickets, west of Braeside; rare.

Asclepiadaceae

151. *Asclepias incarnata* L.
Along Skokie Stream and in various other wet places; common.

Convolvulaceae

152. *Convolvulus sepium* L.
In the swamp meadow and in the meadow; rare.

153. *Cuscuta Cephalanthi* Engelm.
On *Cephalanthus occidentalis,* southwest of Ravinia; seemingly rare.

154. *C. glomerata* Chois.
On *Solidago,* etc., in the meadow and outer swamp meadow; common.

Verbenaceae

155. *Verbena hastata* L.
In the meadow and swamp meadow; occasional.

156. *Lippia lanceolata* Michx.
In outer parts of the reed swamp, west of Highland Park; rare.

Labiatae

157. *Teucrium canadense* L.
In the swamp meadow; rare.

158. *T. occidentale* Gray
Mainly in the reed swamp; abundant.

159. *Scutellaria galericulata* L.
In the reed swamp and swamp meadow; common.

160. *Agastache scrophulariaefolia* (Willd.) Ktze.
In the meadow, near thickets and woods west of Glencoe; rare.

161. *Prunella vulgaris* L.
In the meadow; occasional.

162. *Physostegia formosior* Lunell.
In the reed swamp, west of Braeside; rare. The specimens do not fit descriptions of *P. virginiana* (L.) Benth., but match well the material collected by Dr. Lunell and described by him as new (Lunell, '08, p. 7).

163. *Stachys palustris* L.
In the reed swamp; occasional.

164. *Monarda fistulosa* L.
In the meadow; occasional.

165. *Pycnanthemum flexuosum* (Walt.) BSP.
In the swamp meadow and meadow; apparently rare.

166. *Lycopus americanus* Muhl.
In moist parts of the meadow, in the swamp meadow, and along various ditches; frequent.

167. *Mentha arvensis* L., var. *canadensis* (L.) Briquet
In the reed swamp; common.

Scrophulariaceae

168. *Verbascum Thapsus* L.
Here and there in a few open places of the meadow; rare.

169. *Chelone glabra* L.
In the meadow, near thickets; rare.

170. *Mimulus ringens* L.
In the reed swamp; common.

171. *Gratiola virginiana* L.
In open wet places of the swamp meadow; frequent.

172. *Veronica Anagallis-aquatica* L.
In Skokie Stream; at many points abundant.

173. *V. scutellata* L.
In the reed swamp and swamp meadow; frequent.

174. *V. peregrina* L.
On nude spots of soil in the swamp meadow; frequent.

175. *Pedicularis lanceolata* Michx.
In moist places about thickets; rare.

Plantaginaceae

176. *Plantago major* L.
In the meadow; occasional.

177. *P. Rugelii* Dcne.
With *P. major*, but apparently more frequent.

Rubiaceae

178. *Galium Claytoni* Michx.
In the reed swamp and swamp meadow; abundant.

179. *Cephalanthus occidentalis* L.
In wet thickets; occasional.

Caprifoliaceae

180. *Sambucus canadensis* L.
In thickets, mostly in outer parts of the marsh; frequent.

Campanulaceae

181. *Specularia perfoliata* (L.) A. DC.
On dry nude spots of soil in swamp meadow, in late summer; rather rare.

182. *Campanula aparinoides* Pursh
In certain parts of the swamp meadow, among grasses and sedges; common, especially west of Braeside.

Lobeliaceae

183. *Lobelia cardinalis* L.
In the reed swamp and along certain ditches; common at certain points, especially west of Glencoe.

184. *L. spicata* Lam.
In the swamp meadow; frequent.

Compositae

185. *Vernonia fasciculata* Michx.
About thickets, in the swamp meadow; frequent.

186. *Eupatorium purpureum* L.
In the swamp meadow; occasional.

187. *E. perfoliatum* L.
In the swamp meadow and moist parts of the meadow; frequent.

188. *Solidago canadensis* L.
In outer parts of the marsh, about thickets; common.
Var. *gilvocanescens* is present in similar situations; fairly frequent, at least west of Glencoe.

189. *S. serotina* Ait.
About thickets; frequent.

190. *S. graminifolia* (L.) Salisb., var. *Nuttallii* (Greene) Fernald
In similar situations; frequent. The rootlets of numerous specimens mainly pointing upward toward the soil surface, as if for oxygen.

191. *Boltonia asteroides* (L.) L'Hér.
In the reed swamp and swamp meadow; abundant.

192. *Aster Tradescanti* L.
In the reed swamp and swamp meadow; abundant.

193. *A. salicifolius* Ait.
In a few moist wooded spots near the margins of the marsh, where it is fairly plentiful.

194. *Erigeron philadelphicus* L.
In the swamp meadow; common.

195. *E. annuus* (L.) Pers.
In the meadow; occasional.

196. *E. ramosus* (Walt.) BSP.
In the meadow; occasional.

197. *Xanthium canadense* Mill.
In a few open spots of the meadow and swamp meadow.

198. *Rudbeckia hirta* L.
In the meadow; common.

199. *R. laciniata* L.
In a few moist places, especially near thickets.

200. *Helianthus grosseserratus* Martens
In outer parts of the marsh, near the thickets; frequent.

201. *Bidens frondosa* L.
In open spots of the swamp meadow and along ditches; frequent.

202. *B. vulgata* Greene
In similar situations but apparently less frequent.

203. *B. cernua* L.
In the reed swamp; abundant.

204. *Helenium autumnale* L.
Here and there in a few moist spots; scarcely frequent.

205. *Achillea Millefolium* L.
In the meadow; frequent.

206. *Artemisia biennis* Willd.
In reed swamp and swamp meadow; abundant, at least in 1911, when marsh was fairly dry.

207. *Erechtites hieracifolia* (L.) Raf.
In a few open spots in the swamp meadow; rather rare.

208. *Senecio aureus* L.
In various moist places; frequent.

209. *S. Balsamitae* Muhl.
With *S. aureus*, or in drier soil (where more abundant).

210. *Cirsium altissimum* (L.) Spreng.
In open, fairly dry places in the swamp meadow and the meadow; rare.

211. *C. arvense* (L.) Scop.
A few fair-sized patches in drier parts of the swamp meadow; scarcely frequent.

212. *Taraxacum officinale* Weber
In the meadow; frequent.

213. *Lactuca scariola* L., var. *integrata* Gren. & Godr.
In dry, open spots in the meadow and swamp meadow; occasional.

214. *L. canadensis* L.
In the meadow; frequent west of Braeside and Glencoe.

215. *L. campestris* Greene
In the meadow; frequent west of Braeside and Glencoe.
L. campestris × *canadensis*, an evident hybrid, occurs west of Glencoe among specimens of the two species proper. The plants resemble in general appearance *L. canadensis*, a few of the leaves, however, becoming slightly hispid-setose underneath the midnerve. The corollas in the fresh specimens are a bright blue, closely resembling those of *L. campestris*. Seed gathered in 1911 was planted in 1912 but did not germinate.

216. *L. spicata* (Lam.) Hitchc.
Along certain ditches; occasional.

217. *Prenanthes racemosa* Michx.
In the meadow, west of Glencoe; frequent.

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EXPLANATION OF PLATES

PLATE LXXXVI

Fig. 1. Map of Skokie Marsh; the dotted line represents Skokie Stream.

PLATE LXXXVII

Fig. 2. Skokie Stream at point west of Braeside, looking north. July, 1911.
Fig. 3. Skokie Stream at point west of Glencoe, looking south. July, 1911.

PLATE LXXXVIII

Fig. 4. Average daily evaporation rates in (*a*) center of reed swamp, (*b*) outer part of reed swamp, (*c*) swamp meadow, and (*d*) forest.
Fig. 5. Average daily evaporation rates among *Phragmites communis:* at *a*, 0 cm.; at *b*, 25 cm.; at *c*, 107 cm.; and at *d*, 198 cm.
Fig. 6. Average daily evaporation rates among *Typha latifolia:* at *a*, 0 cm.; at *b*, 25 cm.; at *c* 107 cm.; and at *d*, 175 cm.

PLATE LXXXIX

Fig. 7. *a, Sparganium eurycarpum; b, Sagittaria latifolia; c, Polygonum Muhlenbergii.* July, 1911.
Fig. 8. *Phragmites communis.* July, 1911.

PLATE XC

Fig. 9. *a, Ranunculus delphinifolius; b, Nymphaea advena; c, Sium cicutaefolium; d, Typha latifolia; e, Polygonum hydropiperoides.* July, 1911.

Fig. 10. *a, Acorus Calamus; b, Polygonum Muhlenbergii; c, Galium Claytoni.* July, 1911.

PLATE XCI

Fig. 11. *a, Boltonia asteroides; b, Penthorum sedoides; c, Proserpinaca palustris; d, Ludvigia palustris; e, Callitriche palustris.* July, 1911.

Fig. 12. *a, Asclepias incarnata; b, Poa pratensis; c, Agrostis alba; d, Equisetum arvense; e, Acalypha virginica; f, Eleocharis palustris.* July, 1911.

PLATE XCII

Fig. 13. *a, Lycopus americanus; b, Viola conspersa; c, Viola cucullata; d, Iris versicolor.* July, 1911.

Fig. 14. One of the broad drainage ditches southwest of Skokie Marsh (west of Kenilworth). *Sparganium eurycarpum* abundant on bed. June, 1912.

PLATE XCIII

Fig. 15. Looking east along the county line (Braeside) road, from Skokie Stream. Swamp meadow on either side and *Ulmus americana* conspicuous in the distance. May, 1912.

Fig. 16. Looking west along the road just north of the county line (Braeside) road. One of the ditches. May, 1912.

PLATE XCIV

Fig. 17. Looking north from the bridge west of Winnetka; showing a basin (largely artificial) in which part of the water from the marsh collects, flowing thence southward through the ditch visible in the foreground. June, 1912.

Fig. 18. Looking south in the west part of Skokie Marsh, west of Glencoe; showing the dense growth of sedges, grasses, etc., of the swamp meadow. June, 1912.

PLATE XCV

Fig. 19. Looking south over the swamp meadow, west of Glencoe; showing the later growth of herbs after the mowing of the tall grasses and sedges. August, 1911.

Fig. 20. View west of Glencoe; the reed swamp at this point separated from forest by only about 15 m. June, 1912.

PLATE XCVI

Fig. 21. View in swamp meadow, west of Ravinia; showing one of the characteristic thickets of *Salix longifolia.* June, 1912.

Fig. 22. Swamp meadow west of Glencoe, with *Ulmus americana,* a conspicuous tree in the landscape of the marsh, along ditch, stream, and marsh border. June, 1912.

PLATE XCVII

Fig. 23. View west of Highland Park, where Skokie Stream widens out but is filled with a dense growth of *Sparganium eurycarpum,* etc. The stream is bordered with *Salix* sp., etc. (on reader's left) and *Populus tremuloides, Fraxinus nigra,* etc. (at right). June, 1912.

Fig. 24. Skokie stream west of Glencoe, looking south; showing the numerous plants that grow rapidly upon the stream bed as the water subsides. June, 1912.

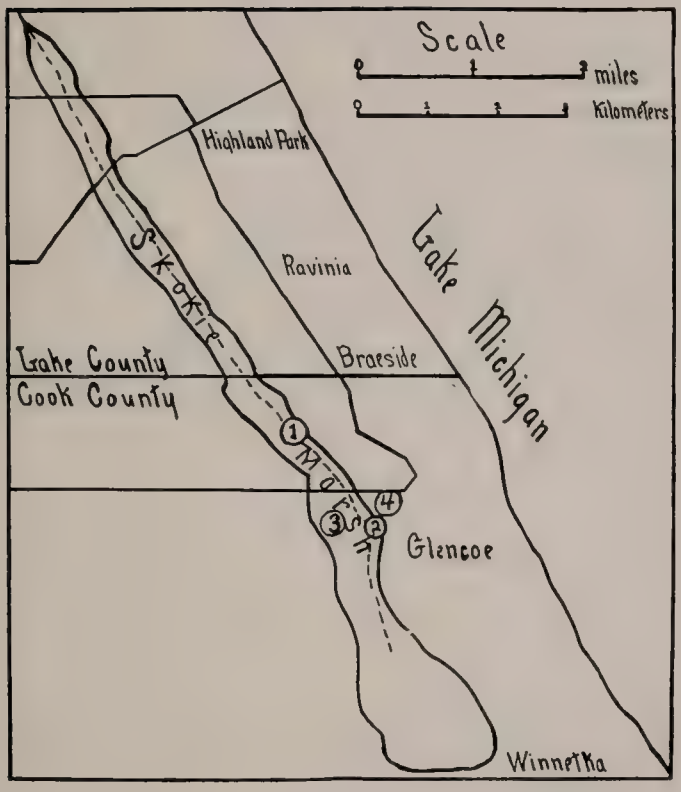
Scale
miles
kilometers
Highland Park
Ravinia
Lake Michigan
Skokie
Lake County
Cook County
Braeside
1
Ma
Fork
2
3
4
Glencoe
Winnetka

FIG. 1

PLATE LXXXVII

FIG. 2

FIG. 3

PLATE LXXXVIII

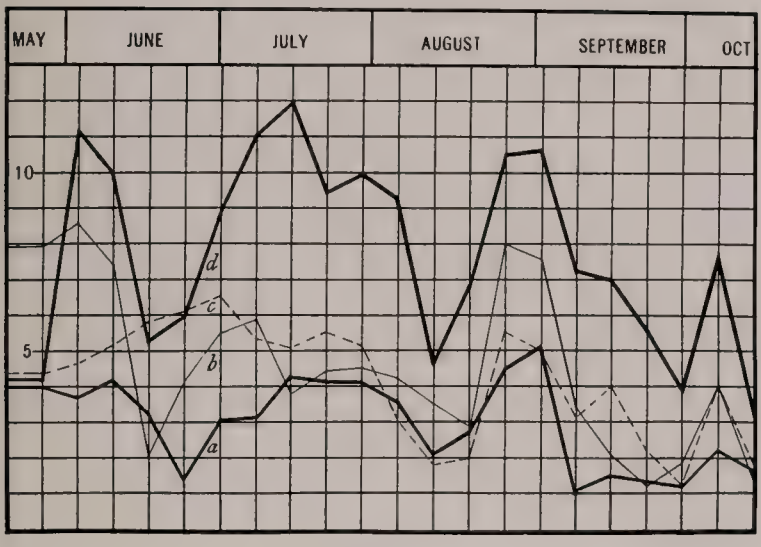

FIG. 4

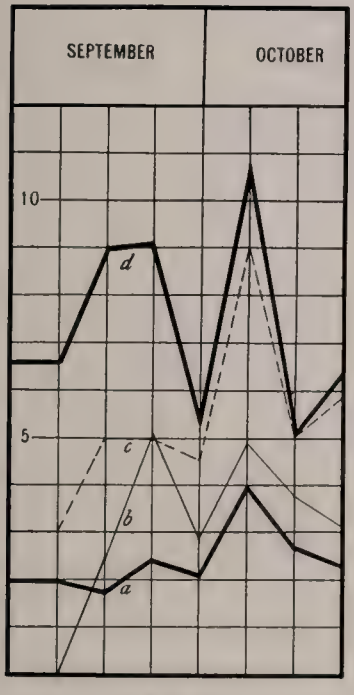

FIG. 5

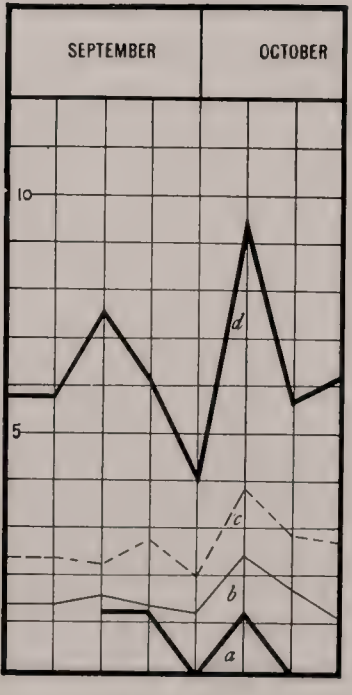

FIG. 6

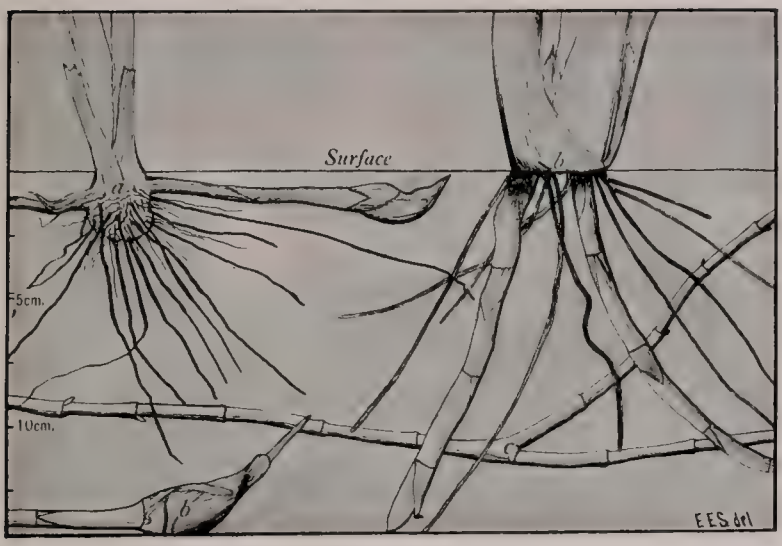

FIG. 7

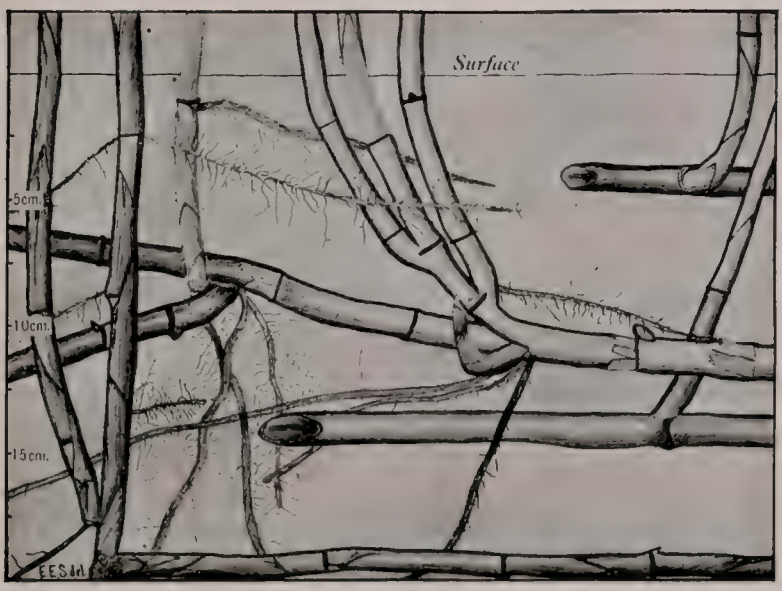

FIG. 8

FIG. 9

FIG. 10

PLATE XCI

FIG. 11

FIG. 12

PLATE XCII

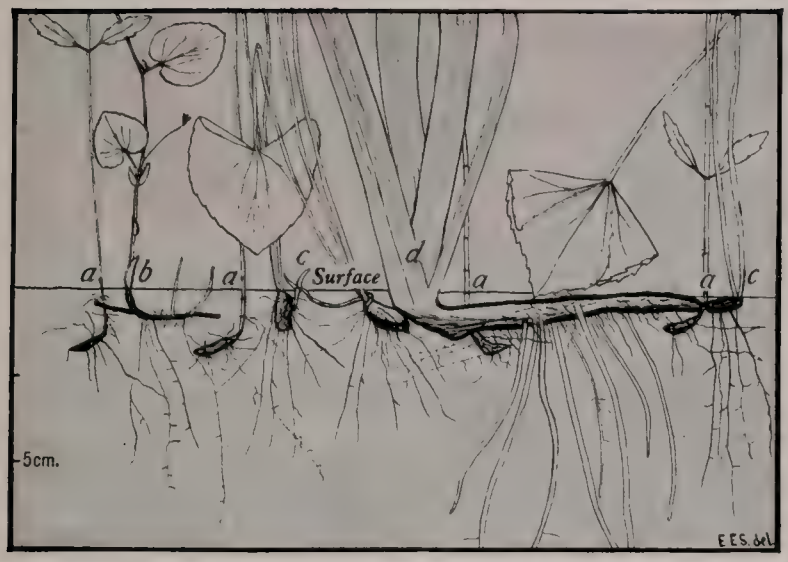

FIG. 13

FIG. 14

FIG. 15

FIG. 16

FIG. 17

FIG. 18

PLATE XCV

FIG. 19

FIG. 20

PLATE XCVI

FIG. 21

FIG. 22

FIG. 23

FIG. 24

BULLETIN

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DIRECTOR

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SOME NEW ILLINOIS ENCHYTRÆIDÆ

BY

FRANK SMITH, A.M., AND PAUL S. WELCH, PH.D.

ARTICLE XII.—*Some New Illinois Enchytræidæ.** BY FRANK SMITH AND PAUL S. WELCH.

Nothing has been published on the *Enchytræidæ* of the Mississippi Valley with the exception of a brief description of *Fridericia agilis* by the senior author nearly twenty years ago ('95, p. 288) and the insufficient account of the problematic forms from Lake Superior by S. I. Smith and Verrill ('71).

In this paper we first describe two new species of *Fridericia* from Urbana, Illinois. The major part of these descriptions was contained in a thesis offered by the junior author in 1911 in partial fulfilment of the requirements for the master's degree from the University of Illinois. We next extend the description of *Fridericia agilis* Smith and add a number of rather important characters not previously given. Finally, we describe a new species of *Marionina* from Urbana, Illinois, which is the first member of this genus reported from the United States. Descriptions of seven other new species of *Enchytræidæ* from the Mississippi Valley will soon appear in a paper by the junior author which is about to go to press.

The drawings for figures 22 to 28 inclusive were made by Mr. S. Fred Prince, illustrator for the Illinois State Laboratory of Natural History. All other drawings were made by the junior author.

FRIDERICIA Michaelsen

About ninety species are assigned to this genus at the present time, making it the largest genus of the family. Of this large assemblage of species only fourteen have been recorded from North America, and only one from Illinois. Four species from the vicinity of Philadelphia, Pennsylvania, one species from Havana, Illinois, and seven species from California constitute the list for the United States. So far as is known the members of this genus are all terrestrial in habit, although they usually occur under somewhat moist conditions.

The genus was established by Michaelsen in 1889, when he discovered that certain species then assigned to *Enchytræus, Neoenchytræus, Mesenchytræus* and *Archienchytræus* had definite characters in common which were of sufficient importance to justify the establishing of a new genus. He defines ('00, p. 106) the genus as follows:

*Contributions from the Zoological Laboratory, University of Illinois, under the direction of Henry B. Ward, No. 22.

"Borsten in 4 Bündeln, gerade, zu 2 im Bündeln und dann gleich lang oder zu mehreren und dann die inneren des Bündeln mehr oder weniger regelmässig paarweise und Stufenweise als die äussern. Rückenporen mit Verschlusszellen meist vom 7., selten vom 6. Segm. an vorhanden. Kopfporus meist klein, dorsal zwischen Kopflappen und 1. Segm. Lymphkörper von zweierlie Gestalt. Peptonephridien stets vorhanden. Der Oesophagus geht allmählich in den Mitteldarm über. Das Rückengefäss entspringt meist postclitellial. Blut farblos. Nephridien meist mit grossem Anteseptale, in dem der Flimmerkanal schon Windungen beschreibt. Samenleiter lang. Samentaschen meist mit dem Darm kommunizierend, einfach oder mit Divertikeln."

Eisen ('05, p. 106) extended the definition by adding the following characters: "Penial bulb without interior muscular strands."... "The intestine in the vicinity of the clitellum contains specialized chylus cells." It remains for future investigation to show whether or not these characters are worthy of generic rank, since in the majority of the species of the genus the penial bulb and the chylus cells have not been studied.

Fridericia firma n. sp.

Definition.—Length, 24–33 mm. Somites, 62–67. Color, whitish yellow. Prostomium blunt. First dorsal pore in VII. Setæ, 4–7 per bundle in anterior part; 4–5 in middle part; 2 in posterior part. Clitellum on XII–XIII. Lymphocytes elliptical, abundant. Brain ¼ longer than wide; anterior margin concave; posterior margin convex. Peptonephridia branching dendritically. Anteseptal part of nephridium slightly smaller than postseptal part; efferent duct arises from mid-ventral surface of latter, near septum. Spermiducal funnel 1.3 to 1.5 times longer than diameter; duct long, slender, and much contorted, and confined to XII. Spermathecæ each with pear-shaped ampulla communicating with digestive tract in V; each ampulla with 3–4 sessile, unequal, lobular diverticula; duct longer than ampulla, slender, and without glands at ectal opening.

The characters of the penial bulb and the chylus cells are not included in the above definition but will be discussed in another part of the paper (pp. 618, 619).

Described from ten sexually mature specimens. Type and paratypes in the collection of the junior author and paratypes in the collection of the senior author.

The specimens which are the basis of this description were found with many others near Urbana, Illinois, in November, 1910, in moist soil under decaying leaves in undisturbed forest land. They were abundant and most of them were sexually mature.

Affinities.—This species is easily distinguished from the other species of the genus. It resembles *F. agilis* Smith ('95, p. 288), *F. longa* Moore ('95, p. 341), and *F. ratzeli* Eisen ('72, p. 123) more closely than it does other members of the genus, but it differs from *F. agilis* in the number of setæ per bundle, the number of diverticula on each spermatheca, and in the characters of the nephridia. It differs from *F. longa* in the characters of the setæ, peptonephridia, and spermathecæ; and from *F. ratzeli* in size, and in the characters of the brain and the spermathecæ.

EXTERNAL CHARACTERS

The body is long, slender, and cylindrical. The average length is about 30 mm., the extremes being 24 and 33 mm. The diameter is greatest at the clitellum (0.6 mm.), gradually decreasing both caudad and cephalad. The intersegmental grooves are rather obscure except in the region just posterior to the prostomium, where a few are quite distinct. No secondary annulations are present. The number of somites varies from 62 to 67. The prostomium (Pl. XCVIII, Fig. 1) is blunt and rounded. The seta bundles in the anterior part of the body each contain 6–7 setæ; those in the posterior part 2–4 each. The proximal ends (Pl. XCVIII, Fig. 2), especially of the more fully developed setæ, are strongly bent.

INTERNAL CHARACTERS

Body Wall.—The cuticula, though comparatively thin, is tough and firm, and offers the chief difficulty in the dissection of alcoholic specimens; but when once broken, it can be easily stripped from the body. It has a luster, in both surface and sectional views, which gives it a glistening appearance. It is of about the same thickness throughout the length of the body. It is reflected into the mouth and lines the digestive tract as far as the openings of the peptonephridia, being continued into the latter for a short distance. It lines the canal of the head pore for most of its length, but is merely perforated at the dorsal pores. The comparative thinness of the cuticula is probably attributable to the fact that this species lives in moist earth. According to Vejdovský ('79, p. 11) such forms as *Anachæta,* which live in dry surroundings, have a very thick cuticula, while in those living in water or in very moist earth it is thin and delicate. It was noticed that the mortality in this species was very high when the earth surrounding the specimens approached dryness, or when they were exposed for a short time to the open air.

The clitellum is on XII and XIII and is distinctly developed. The cells (Pl. XCVIII, Fig. 3) are all of the same kind. The first dorsal pore is in VII, and each pore has a mid-dorsal position in the middle of its somite lengthwise.

Brain.—The brain (Pl. XCVIII, Fig. 4) is in the anterior part of II but projects slightly into I. The length is about one and one fourth times the width. The anterior margin is moderately concave, while the posterior margin is strongly convex. The lateral margins are nearly parallel. Two pairs of supporting strands extend from the lateral margins to the body wall.

Peptonephridia (Salivary Glands).—A pair of these organs open into the ventral side of the digestive tract in the anterior part of IV, close to the septum. They extend caudad through IV and V and a short distance into VI. Each gives off a number of branches at irregular intervals throughout its length.

Chylus Cells.—The chylus cell region is that part of the intestine included in XIII–⅓ XVIII. Here the intestine is lined with the layer of ental epithelial cells, which are ciliated and approximately rectangular in section, and each of these cells contains a large spherical nucleus. The chylus cells lie deeper in the intestinal wall, and open between the cells of the ental layer into the lumen of the intestine. They are long, rather narrow, and broader at the bases than at the apices. The intracellular canal (Pl. XCVIII, Figs. 6, 7) is ciliated and nearly straight in the apical part, but elsewhere it is nonciliated and somewhat tortuous, especially in the broad basal part. It is surrounded by a definite layer of cytoplasm of uniform thickness, which is more hyaline and stains more intensely than the finely granular and deeply staining adjacent part. The two kinds of cytoplasm are sharply differentiated. The elliptical nucleus lies in the base of the cell in the angle formed at the chief bend of the canal. The cell walls are indistinct, and it is somewhat difficult to determine the exact line of demarcation between adjacent cells. However, sufficient details of structure can be made out to prove that these cells are definite units and that each canal is confined entirely within the limits of a single cell. There is some variation in the form of the chylus cells, since near septa and sometimes in the lateral walls of the intestine they are rather short, while between septa they may be rather long and slender. However, in all cases the general structure and the arrangement of parts are uniform. Interstitial cells are absent. Certain considerations relating to the chylus cells will be taken up in another part of the paper (p. 626).

Nephridia.—The first pair of nephridia are related to VI/VII. The anteseptal part (Pl. XCVIII, Fig. 5) of each nephridium is

slightly smaller than the postseptal part. The efferent duct arises from the ventral surface of the latter close to the septum. The lumen is more or less contorted in both anteseptal and postseptal parts.

Spermaries.—The spermaries are in the usual position in XI. In most of the preparations the germ cells show various stages of mitotic division. In sexually mature specimens a large mass of developing sperm cells nearly fills the somite, often pushing the septa into contact with septa IX/X and XII/XIII.

Sperm Ducts.—The spermiducal funnel (Pl. XCVIII, Fig. 8) is nearly cylindrical, and the length is approximately one and one half times the diameter. It is situated in the posterior part of XI with the base in close proximity to the ventral part of XI/XII, and the long axis is directed obliquely dorsad. The anterior end has a well-differentiated reflected collar, distinctly set off from the body of the funnel by a constriction. The sperm duct is rather long, contorted, and confined to XII.

Penial Bulb.—The penial bulbs (Pl. XCIX, Figs. 9, 10) are in close relation to the penial pores* and each is involved in a very material modification of the body wall. At each penial pore there is a deep invagination and an interruption of the muscle layers. The character of the hypodermis is abruptly altered, but the cuticula, slightly reduced in thickness, is reflected into the invagination as a lining. The body of the bulb is composed of two kinds of cells: (1) large, glandular cells which occupy all of the dorsal and peripheral parts of the bulb and have large spherical nuclei; and (2) long, narrow, columnar cells which are situated in the interior of the bulb and are arranged radially around the penial lumen* for its entire length. Cells of the second type contain small ovoid nuclei at their inner ends and stain very lightly. They merge gradually into ordinary hypodermal cells at the ventral side of the bulb, which, in turn, give place to the clitellar cells present in the mid-ventral region. The bulb is covered by a well-developed musculature which is a continuation of the circular muscle layer of the body wall.

The bulb is a typical lumbricillid bulb as defined by Eisen ('05, p. 8). He claims that this organ has taxonomic importance and can be used in the characterization of species, genera, and subfamilies. The structure of the bulb agrees also with his diagnosis of the genus

*We shall not undertake a discussion of the homologies of the penial bulb, but for the purposes of this paper shall designate the ectal opening of its lumen as the *penial pore* (Pl. XCIX, Fig. 10, *pen. po.*) instead of the spermiducal pore, and the lumen itself (Fig. 10, *pen. lum.*) as the *penial lumen.* This latter is the same as Eisen's "extension of the sperm duct" and "elongation of the sperm duct" ('05, pp. 108 and 8).

Fridericia and the subfamily *Lumbricillinæ*, based on the character of the penial bulb. The discussion of the importance of this organ in classification is taken up in detail in another paper to be published in the near future.

Spermathecæ.—Each spermatheca (Pl. XCIX, Fig. 11) consists of three distinct parts; an ampulla, diverticula, and the duct. The ampulla, the largest part of the spermatheca, is a pear-shaped organ, of which the smaller end is united with the digestive tract in the posterior part of V, and the larger end is connected with the body wall by means of the duct. The cavity within conforms somewhat to the external shape of the organ, being rather spacious in the region of the diverticula, and gradually narrowing to the point where it communicates with the lumen of the digestive tract. The communications of the two spermathecæ with the digestive tract are separate. Three or four sessile lobular diverticula are present on the ectal end of the ampulla. They are somewhat similar in shape but vary in size. The duct originates at one side of the ectal end of the ampulla from a cone-shaped expansion. It is uniform in diameter, about three times as long as the ampulla, and is lined with cuticula throughout its entire length. The ectal opening is lateral in position and near the intersegmental groove IV/V. No accessory glands are present at the ectal opening. The hypodermis of IV and V, with the exception of the dorsal third, is strongly thickened, the thickening being greatest in the vicinity of the spermathecal pores.

Fridericia tenera n. sp.

Definition.—Length, 9–17 mm. Somites, 52–59. Color, whitish. Prostomium rounded. First dorsal pore in VII. Setæ, 4–6 per bundle in anterior region of body; 2–4, usually 2, in posterior region. Clitellum on XII and XIII. Lymphocytes elliptical. Brain about one fifth longer than wide; anterior margin concave, posterior margin convex, lateral margins converge cephalad. Peptonephridia each with several branches originating from common base, and some secondary branches. Anteseptal and postseptal parts of nephridia about equal in size; efferent duct arises from mid-ventral surface of postseptal part near septum. Spermiducal funnel about twice as long as wide; duct long, much contorted, and confined to XII. Spermathecæ each with barrel-shaped ampulla communicating with digestive tract in V, and each bearing about seven globular sessile diverticula; two glands at ectal opening of spermathecal duct.

For discussion of penial bulb and chylus cells see pages 622, 623.

Described from seventeen sexually mature specimens. Type and paratypes in the collection of the junior author; paratypes in the collection of the senior author.

The specimens which form the basis of this description were found in a compost pile in the forest grounds of the University of Illinois and were collected in October and November, 1910.

Affinities.—This species seems to approach several other species, namely, *F. lobifera* Vejdovský ('79, p. 57), *F. udei* Bretscher ('99, p. 411), *F. beddardi* Bretscher ('00, p. 29), *F. macgregori* Eisen ('05, p. 118), and *F. californica* Eisen ('05, p. 119). Because of brevity, use of general terms, and indefinite statements, the descriptions of *F. udei* and *F. beddardi* are somewhat puzzling and comparisons troublesome, but the aggregate of differences is such that it is not difficult to separate *F. tenera* from them. It differs from *F. lobifera* in length, and in the characters of the brain, peptonephridia, and spermathecæ; from *F. udei* in length, and in the characters of the peptonephridia, spermathecæ, and nephridia; from *F. beddardi* in the characters of the peptonephridia, brain, and spermathecæ; from *F. macgregori* in length, number of somites, and in the characters of the brain and spermathecæ; and from *F. californica* in length, number of somites, and the characters of the brain and spermiducal funnel.

In connection with the above comparison a certain discrepancy which appears in Eisen's description of *F. macgregori* should be noted. In his description of the brain, he says, "Brain anteriorly much convex; posteriorly slightly so." His text figure of the brain shows that the anterior margin is less convex than the posterior. It seems probable that the figure is correct.

EXTERNAL CHARACTERS

The worms are relatively slender and delicate, having a length of 9–17 mm., and a maximum diameter of only about 0.4 mm. The number of somites varies from 52 to 59. The living worms are opaque and whitish in appearance. The clitellum is on XII and XIII and is only moderately developed. It is made up of transverse rows (Pl. XCIX, Fig. 13) in which glandular cells alternate with clear ones. The intersegmental grooves are obscure, except the first four or five. The setæ are of the typical *Fridericia* type and are relatively large. The distal ends are sharply pointed, and the proximal ones (Pl. XCIX, Fig. 14) are strongly recurved. In the anterior part of the body the dorsal bundles contain 4–5 setæ, the ventral ones usually 6; in the middle region both sets of bundles contain 4 setæ; while in the posterior part, 2 is the predominating number.

INTERNAL CHARACTERS

Body Wall.—The hypodermis contains unicellular flask-shaped gland cells (Pl. XCIX, Fig. 16) which are numerous and generally distributed. They occur among the ordinary hypodermal cells, and each opens at the surface through the distal narrowed neck region. They are much larger than the hypodermal cells though shorter. They are approximately uniform in shape except in the thickened region of the first somite and the prostomium, where they are more elongate. The contents show a certain degree of polarity. In the ectal part of the cell the contents are of such a nature that they stain only slightly, while the opposite end is filled with material which stains deeply. The latter also contains a conspicuous nucleus.

Brain.—The brain (Pl. XCIX, Fig. 15) lies entirely in II and is about one fifth longer than wide. The anterior margin is concave; the posterior margin is convex; and the lateral margins are gradually convergent anteriorly. Two pairs of supporting strands connect the lateral margins of the brain with the body wall.

Peptonephridia.—A pair of these organs open into the ventral side of the digestive tract in IV. Each is composed of several branches which arise from a common base, and most of which are directed caudad and terminate in VI. Secondary branching exists to some extent.

Chylus Cells.—The chylus cell region is that part of the intestine included in XV–XVII. The chylus cells (Pl. C, Fig. 18) are flask-shaped, and each cell contains the characteristic intracellular canal, which has a somewhat sinuous course, especially in the ectal end of the cell. The canal is ciliated throughout almost its entire length. There seems to be no special modification of the cytoplasmic layer surrounding the canal, such as exists in *F. firma* and some other species. Each cell contains a conspicuous nucleus, which usually lies in the chief bend of the canal. Between the apical ends of the chylus cells are fitted the wedge-shaped ental epithelial cells. The location of the chylus cells in XV–XVII is different from that in any other species in which they have been described and may, in accordance with the general view of Eisen, be a valid specific character.

Nephridia.—The first pair of nephridia are connected with V/VI. The anteseptal and postseptal parts (Pl. C, Fig. 17) are about equal in size. The efferent duct arises from the mid-ventral surface of the postseptal part, near the septum, and opens to the exterior slightly anterior to the corresponding ventral setæ. The lumen is tortuous throughout its whole length.

Penial Bulb.—In many respects the structure of the penial bulb (Pl. C, Fig. 20) in this species is similar to that of *F. firma*, although a number of distinct differences are apparent. Unlike that of the latter species the body of the bulb is composed of cells of but one kind. They are large and glandular, and each contains a large, conspicuous nucleus at the peripheral end. Each cell has a prolongation which extends to the penial lumen. The peripheral part of the cell stains deeply but the prolongation stains only very slightly. The sperm duct enters the bulb at the anterior end and extends obliquely ventrad, opening into the penial lumen. Figure 20 shows the structural detail of this organ as it appears in a transverse section of the worm. This bulb is clearly of the lumbricillid type as defined by Eisen. It differs from that of *F. firma* in lacking the inner bulb cells which surround the penial lumen.

Spermathecæ.—Each spermatheca (Pl. C, Fig. 21) is differentiated into ampulla, duct, and several diverticula. The ampulla is somewhat elongated and inflated in the middle. The ectal end bears a circle of globular sessile diverticula, usually seven in number and slightly dissimilar in shape and size. The duct arises from the center of this circle of diverticula and extends, with few curves, to its ectal opening in the lateral wall of the body slightly posterior to IV/V. Two pear-shaped glands are present at the ectal opening. The cuticula is reflected into the lumen of the duct and lines it for its entire length.

Fridericia agilis Smith

At the time that this species was described*, certain organs of the *Enchytræidæ* were not considered of as much systematic importance as at present, and, accordingly, they were ignored, or received scant attention in the description of *F. agilis*. In view of the large number of species of the genus already known and of the large number that are almost sure to be made known in the future, it is important that descriptions should be quite detailed. For this reason an examination of additional material and a further study of old material have been made and a more extended description prepared, no attempt being made to distinguish the old material from the new.

Definition.—Length, 25–30 mm. Diameter, 0.63–0.82 mm. Somites, 57–66, average, 62. Color, whitish. Prostomium blunt and rounded. First dorsal pore in VII. Setæ, 2–4, usually 2, per bundle. Clitellum on XII–XIII. Lymphocytes numerous, broadly elliptical.

*In 1895, in the Bulletin of the Illinois State Laboratory of Natural History, Vol. IV, Art. VIII, pp. 288-289.

Brain one half longer than greatest width; anterior margin slightly concave, posterior margin quite convex. Peptonephridia large, very much branched, opening into digestive tract in posterior part of III. Dorsal vessel arises in XIX. Nephridia with anteseptal part equaling postseptal part in size; efferent duct arises from posterior end of latter. Spermiducal funnel twice as long as its diameter. Spermathecæ each with duct, ampulla, and diverticula; duct about three times as long as ampulla, with a few very small unicellular glands at ectal opening; ampulla with about nine similar, globular diverticula.

For discussion of penial bulb and chylus cells see pages 625, 626.

Described from twelve sexually mature specimens. Type in the collection of the Illinois State Laboratory of Natural History. Paratypes in the collections of each of the authors.

The specimens on which the description of this species is based were collected at Havana, Illinois, in April and May of 1895. They were found abundant in the wooded banks and bottom-lands of the Illinois River, under logs and in the damp rich soil, mingled with decaying vegetation.

EXTERNAL CHARACTERS

The body of the worm is smooth, rather robust, cylindrical, tapering very gradually towards the two extremities. The length of mature specimens is 25–30 mm. The diameter is greatest in the region of the clitellum, where, in alcoholic specimens, it is 0.63–0.82 mm. The number of somites varies from 57 to 66. The intersegmental grooves, except the first four or five, are indistinct. The intersegmental groove IV/V differs from the adjacent ones in being broader and more shallow. The prostomium is blunt, rounded, and smooth. The color of the living worm is whitish. The clitellum, which is on XII–XIII, is moderately developed and composed of cells of but one kind. The setæ vary from 2 to 4 per bundle, the more usual number being 2. Each seta is rather strong, acute at the distal extremity, and distinctly bent at the proximal end.

INTERNAL CHARACTERS

Lymphocytes.—The lymphocytes are abundant in most parts of the body. They are broadly elliptical in outline, and the long axis of each averages about 0.025 mm.

Brain.—The brain (Pl. C, Fig. 22) is in I and II. The anterior margin is slightly concave, the posterior margin is quite convex, and the lateral margins are almost parallel. In transverse section it is ovoid. A pair of supporting strands extending from the latero-

posterior parts of the brain in a latero-caudal direction attach it to the body wall.

Peptonephridia.—A pair of these organs connect independently with the ventral side of the digestive tract in the posterior part of III. The apparent absence of septum III/IV makes it difficult to determine the exact point of separation between III and IV. These glands open into the digestive tract very close to III/IV, apparently in the posterior part of III. They are directed caudad and do not extend beyond IV/V. Each branches profusely and in an irregular, dendritic fashion.

Chylus Cells.—Chylus cells (Pl. C, Fig. 23) are present in the walls of the intestine in ⅔ XII–XVI. They are somewhat flask-shaped, the ectal ends being broader than the ental ones. They vary in form considerably, the length of some being nearly three times their diameter, while in others it is but little greater. It is possible that these ratios are subject to change in the same cell, owing to the different states of contraction of the intestinal wall. The ental part of the intracellular canal is straight; the basal part is sinuous and somewhat branched. Cilia are present throughout the greater part of the ental portion of the canal, and are directed toward the lumen of the intestine. The canal is lined by a specialized layer of cytoplasm, which is everywhere uniform in thickness and structure. The perivisceral blood sinus comes into contact with the basal portion of each chylus cell. The cells of the ental epithelial layer are wedge-shaped, and usually occur singly between the apices of the chylus cells. The ental surface of these cells is thickly covered with long cilia. Interstitial cells are absent.

Eisen ('05) made careful studies of these peculiar cells in a number of species which he described from the west coast of North America and was convinced that their location, form, and size furnish good specific characters. Since other students of *Fridericia* have not described these structures in any detail, Eisen's conclusions were necessarily based on an investigation of but a small number of the many known species, and more extended studies must be made before his views can be justly weighed. The characters of the chylus cells in *F. firma, F. tenera,* and *F. agilis* do not coincide with those of any other species in which such cells have been described, but appear to present distinct specific differences.

Nephridia.—The anteseptal and postseptal parts (Pl. CI, Fig. 24) of each nephridium are approximately equal in size, and both are well developed. The efferent duct arises from the posterior end of the postseptal part. The true origin (Pl. CI, Fig. 25) of the duct is

occasionally obscured by a peculiar modification of the nephridium in which the posterior half of the postseptal part is bent ventrad and cephalad, and is in such close relation to the ventral side of the anterior half that the origin seems to be near the septum.

Spermiducal Funnel.—The spermiducal funnel (Pl. CI, Fig. 26) is very large, and the two funnels occupy the greater part of the cœlom in XI. They are barrel-shaped and about twice as long as their diameter. Each has a distinct reflected collar set off from the body of the funnel by a constriction. The diameter of the collar is less than the maximum diameter of the funnel. The sperm duct is long, slender, and confined to XII.

Penial Bulb.—The structure of the penial bulb (Pl. CI, Fig. 27) so closely resembles that already described for *F. firma* that it seems unnecessary to give a detailed description. The shape, relative size, musculature, and relation to the body wall are all about the same as in that species. Similarly, also, the body of the bulb is composed of two distinct sets of cells, viz., the inner bulb cells, which immediately surround the penial lumen, and the peripheral bulb cells, which comprise the greater part of the mass of the organ. The relation of the bulb to the sperm duct is also similar to that described for *F. firma.*

Spermathecæ.—Each spermatheca (Pl. CI, Fig. 28) has a distinctly differentiated duct and ampulla, the latter bearing diverticula. The duct is slender and about three times as long as the ampulla. It unites with the ectal end of the latter at the middle of the ring of diverticula and extends, with few curves, to the ectal opening, which is laterad and near IV/V. A few inconspicuous gland cells are present about the ectal opening. The ampulla is barrel-shaped and thick-walled. It bears a ring of about nine similar lobular diverticula at the ectal end. The walls of the diverticula are comparatively thin, and the lumina are in direct communication with the lumen of the ampulla. The spermathecæ communicate independently with the digestive tract on its dorsal side in the posterior part of V. The spermathecæ are quite large and occupy a considerable part of the space in V.

The Function of the Chylus Cells in Fridericia

The homologies and functions of these peculiar cells are, indeed, quite problematical. The intimate connection of the cells with the digestive tract and their close contact with the blood vascular system indicate that they have an important rôle in some metabolic process. Michaelsen ('86, p. 296) has maintained that they are organs of absorption. Eisen ('05, p. 107) also favored this interpretation, and at-

tempted to support it by the assumption that the presence of the cilia in the canal indicates that the canal itself is simply an invagination of the ciliated apical surface of the cell, and that a means is thus provided for bringing the nutritive fluid into close relation with the blood sinuses at the base of the cell. He further held that the probable function of the cilia in the apical end of the canal is to facilitate the introduction of the nutritive fluid, and that the canal is the means whereby greater intestinal surface and rapid absorption are insured without consequent diminution or weakening of the intestinal wall.

Vejdovský ('06, p. 65) and Čejka ('10, p. 17) assign a secretory function to these cells, and assume that the cilia aid in the passage of the secretion from the canal into the lumen of the alimentary tract. They also claim that the cells are produced by modifications of the deeper-lying cells of the epithelium and that, in sections, intermediate stages in such a development can be seen.

We have made no observations which enable us to contribute directly to the determination either of the function or of the mode of origin of these cells, but have made some observations on the arrangement of the cilia of the canals and offer some suggestions as to their probable function.

We have numerous sections of specimens from each of the species of *Fridericia* herein described which show clearly that the cilia of the canal are directed towards the opening at the apical end as represented by Vejdovský, and have found no instance in which they extend in the opposite direction as figured by Eisen ('05, Pl. XVII and XX). We believe that the cilia may have a function quite different from the one previously assumed.

Experiments and observations by Cuénot, although not dealing directly with this subject, throw light on the problem in an interesting way. He has shown ('97, p. 105) that the vibratile cilia in the nephrostome of the nephridium of *Oligochæta* can not introduce the *cœlomic* fluid into the interior of the nephridium except when inequalities in the fluid pressure in the lumen will permit. Furthermore, he has shown that solid bodies in suspension in the cœlomic fluid can not pass through the orifice of the nephrostome because the thickly set cilia play the rôle of a sieve or filter and form an impassable barrier to any solid particles, except possibly those which are excessively minute. In view of these facts it seems probable that the prime function of the cilia of the nephrostome is the prevention of the passage of solid particles into the nephridial lumen rather than the introduction of fluids into the lumen as has been assumed.

It seems, then, reasonable to infer that the cilia in the apical part of each chylus cell canal also function as a filter, preventing the in-

troduction of solid particles from the intestine, and that they do not induce a flow of fluid into the lumen as claimed. No experimental evidence has yet been secured to substantiate this inferential view but it seems plausible. For some reasons there is even a better basis for ascribing this filtering function to the cilia of the chylus cells than to those of the nephridia. In the first place, the canals of the chylus cells end blindly, while the nephridial canals have external openings and in consequence the nephridial lumen may sometimes be almost or entirely empty, when, as claimed by Cuénot, it is possible for the cilia of the nephrostome to aid in the introduction of the fluids. On the other hand, the chylus cells occur in a part of the intestine where, under normal conditions, the nutritive fluid is constantly present. Since the intracellular canal of each cell has but one opening, the canal is presumably at all times filled with fluid, the amount of which is far more dependent on pressure conditions in neighboring parts than on any action of the cilia. The powerful and frequently changing muscular contractions in various parts of the body are accompanied by more or less violent disturbances of pressure and consequent movements in the fluid contents. It seems reasonable to assume that such disturbances would more profoundly affect the extensive digestive tract and its contents than the diminutive nephridium, which is to such a considerable extent freely suspended in fluid. In the second place, the apical ends of the chylus cells are exposed to great quantities of solid particles, since the contents of the digestive tract must pass by them, and yet none of the preparations examined by us have shown any indication of the presence of such material in the canals. Unless there were some provisions for the prevention of the entrance of solid matter these blind canals would be almost sure to contain such material and their functional efficiency be correspondingly reduced.

MARIONINA Michaelsen

During the autumn of 1895 a study of the animal life in the waterworks reservoir of Urbana, Illinois, was made by Miss Bertha V. H. Forbes, a student in the University of Illinois, and in her collections were a moderate number of small enchytræid worms. They were turned over to the senior author of this paper and were partly worked up at that time, but circumstances prevented the completion of the work, and nothing further was done with the worms until the present year, when their further study was undertaken by the junior author. They proved to be an undescribed species of *Marionina*.

This is not only the first record of a species of *Marionina* for Illinois, but it is also the first time a representative of this genus has been reported from the United States, although Eisen ('05) has described two new species from Alaska.

The genus *Marionina* was established by Michaelsen in 1889. Previous to that time forms belonging to this genus were scattered among a number of the older genera, the old genus *Pachydrilus* (*Lumbricillus*) receiving the larger part.

Michaelsen ('00, p. 73) defines the genus *Marionina* as follows: "Borsten S-förmig gebogen. Rückenporen fehlen; Kopfporus klein, zwischen Kopflappen und 1. Segm. Das Rückengefäss entspringt postclitellial und besitzt kein Herzkörper. Peptonephridien fehlen. Hoden massig. Samenleiter lang. Samentaschen ohne Divertikel." Eisen ('05, p. 90) has extended this definition somewhat: "Setæ sigmoid, as in Lumbricillus. Head pore small, between the prostomium and somite I. No dorsal pores. Blood red or yellow. Dorsal vessel rises posterior to clitellum. No cardiac gland. No peptonephridia. Sperm-ducts comparatively long and narrow. Penial bulb without interior muscular strands. Testes undivided, each covered with a small sperm-sac. Ventral glands present or absent. Nephridia with entire postseptal and with comparatively large head-like anteseptal."

The close similarity between the definition of *Marionina* and that of *Lumbricillus* is apparent, the chief difference being the presence of multilobed testes in the latter. Eisen ('05, p. 90) thinks that another difference may be derived from the nephridium, "which in Marionina seems to be characterized by a long head-like anteseptal, while in Lumbricillus the anteseptal consists of merely the nephrostome." There are insufficient grounds for giving such a character generic rank, since the anteseptal part of the nephridium in *Marionina* is quite variable. In *M. werthi* Mchlsn., *M. falclandica* Mchlsn., and in several other species, the anteseptal part consists of the nephrostome only.

Marionina is one of the smaller genera of the family *Enchytræidæ*. At present twenty-six apparently valid species are assigned to it, of which only two have been recorded for North America. They are *M. alaskæ* Eisen and *M. americana* Eisen, both from Port Clarence, Alaska.

Marionina forbesæ n. sp.

Definition.—Length, 5–6 mm. Diameter, 0.221–0.238 mm. Somites, 25–28. Setæ slightly sigmoid; those of a bundle equal in size; 2–4 per bundle. Clitellum on XII–XIII; developed only on

dorsal and lateral surfaces. Prostomium slightly pointed. Head pore on o/I. Cuticula very thick and resistant. Lymphocytes few in number, oblong, nucleated, cytoplasm heavily granular in appearance. Brain about twice as long as wide; anterior margin conical, posterior margin emarginated, lateral margins convergent anteriorly. Peptonephridia lacking. No ventral glands. Septal glands in IV--VI. Dorsal vessel arises in XIII. Blood yellowish. Anteseptal part of nephridium a mere nephrostome; postseptal part large, flattened laterally, efferent duct arising from its ventral side near posterior end. Spermatheca with distinct duct and ampulla; ampulla pear-shaped; not connected with the intestine and with no diverticula; duct narrow, rather short, with no glands at ectal opening. Length of spermiducal funnel about twice its diameter. Testes undivided; sperm sacs lacking.

For a discussion of the penial bulb see page 632.

Described from five sexually mature specimens, although a number of others were examined in connection with the study on the living forms. The type and a paratype are in the collection of the junior author, and paratypes in that of the senior author.

The above specimens which form the basis of the description of this species were found in the mud and settlings in the bottom of the waterworks reservoir of Urbana, Illinois. At the time of collection they occurred only in moderate numbers. The dates of collection range from October 23 to November 26, 1895. The species name is given in recognition of the discoverer, Miss Bertha V. H. Forbes.

EXTERNAL CHARACTERS

The specimens are small, their length being only 5–6 mm. The figures given are for the living specimens and apply to all the sexually mature individuals. As measurements of alcoholic material gave almost exactly the same result, it appears that in this species of the *Enchytræidæ* authentic data regarding length can be secured from the examination of preserved material. This fact may be due to the exceptionally thick and resistant cuticula, which may perhaps also account for the fact that living specimens have but a slight range in contraction and extension. The number of somites varies from 25 to 28. The body is cylindrical, and the diameter is approximately uniform for almost its entire length, only the first somite and the last two or three showing gradual increase in size. The diameter varies from 0.22 to 0.24 mm. The clitellum is on XII–XIII and is slightly developed dorsad and laterad but is interrupted on the ventral surface of the body. The prostomium (Pl. CI, Fig. 29) is rounded, yet

slightly pointed. The head pore is present at o/I. The anterior four or five intersegmental grooves are distinct, but beyond this region they are obscure. Three to eight secondary transverse grooves occur on all of the somites posterior to II or III with the exception of XII and XIII.

A conspicuous feature of living specimens is the presence of definitely arranged spots on the external surface. They are disposed in transverse rows, 2–3 per somite, each row containing 2–4 spots. One row is slightly anterior to the setæ, another slightly posterior to them, and a third caudad to the latter. These markings do not appear in alcoholic specimens.

Setæ.—The setæ are slightly sigmoid, but in an examination of the living material or of specimens mounted *in toto* it is very easy to overlook their slightly sigmoid form and to mistake them for straight setæ. Transverse sections of the worm (Pl. CII, Fig. 31) reveal the curves distinctly. The setæ are arranged in four bundles per somite, two ventral and two lateral. The number of setæ per bundle varies from 2 to 4. In the anterior region the numbers 4 and 3 seem to predominate, while in the posterior region there are usually 3 per bundle, and but 2 in the last one or two somites. The distal extremities of the setæ of each bundle are all curved in the same direction, those of the lateral bundles curving ventrad and those of the ventral bundles curving dorsad. The proximal ends of the setæ also show a slight curvature in a direction opposite to that of the distal portion.

Cuticula.—There is a very thick resistant cuticula of which the thickness is about equal to that of the combined thickness of the hypodermis and the muscular layers of the body wall. This cuticula is so resistant that in some cases it caused considerable trouble in sectioning. It appears to be approximately uniform in thickness throughout the length of the body.

INTERNAL CHARACTERS

Lymphocytes.—The lymphocytes are scattered sparingly throughout the greater part of the cœlom. They are nucleated and the cytoplasm is granular. The shape varies from an oval to a decidedly oblong form, and the length of some lymphocytes is about twice that of others (Pl. CI, Fig. 30).

Brain.—The brain lies in I, II, and III, chiefly in II. Its length (Pl. CII, Fig. 32) is approximately twice the greatest width. The anterior margin is decidedly conical; the posterior margin is conspicuously emarginate; and the lateral margins converge anteriorly.

In transverse section it is ovoid in shape. Studies on the living specimens revealed the fact that the depth of the posterior emargination is subject to some variation, depending upon certain changes in the states of contraction of the animal. Sometimes the emargination is rather shallow, although always distinct; at other times the emargination is deep. Two pairs of strands connect the brain with the body wall, one pair arising from the lateral margins of the brain and the other pair from the posterior lobes.

Blood Vascular System.—Studies of both living and preserved specimens show that the dorsal vessel arises in XIII. A distinct swelling of this vessel occurs in XIII, where the diameter exceeds that of any other region. No cardiac body is present. The perivisceral sinus appears in the region of the clitellum, and in transverse sections of the worm has a distinctly beaded appearance entirely around the intestine. There is reason to believe that this appearance is due to the fact that there are membranous partitions which run lengthwise of the sinus, thus dividing it into a number of longitudinal tubes. These tubes appear to be distended with blood, and when sectioned transversely exhibit a more or less circular outline. This sinus extends posteriorly from the origin of the dorsal vessel, and shows a decided reduction at the septa. The ventral vessel branches at IV/V. The blood is yellowish in the living specimens.

Nephridia.—The first nephridia are connected with VII/VIII. The anteseptal part (Pl. CII, Fig. 33) is very small and consists merely of the nephrostome. The postseptal part is large, elongated posteriorly, and flattened laterally. The efferent duct arises from the ventral side of the postseptal part, slightly anterior to its posterior end.

Spermiducal Funnel.—The spermiducal funnel is about twice as long as its average diameter. In some specimens the funnel is slightly flattened laterally. A set of typical measurements are as follows: length 0.07 mm; average diameter 0.039 mm. The duct is very long, much contorted, and confined to XII.

Penial Bulb.—This organ is well developed, and is rather conspicuous in transverse sections. It is situated on a distinct invagination of the body wall. It is globular in shape (Pl. CII, Fig 34), particularly in cases where it is extruded. In the retracted condition it is ovoid. The organ as a whole is covered with a thin peritoneal layer, beneath which lies a comparatively thin layer of muscle tissue. The body of the bulb is composed of a large number of similar, more or less spindle-shaped cells, whose long axes extend towards the external surface. Each cell is conspicuously nucleated and usu-

ally the cell walls are distinct. When retracted, the duct enters the bulb well down on the ental side and extends through it to the exterior opening at the edge of the invagination. In the everted condition the lateral part of the bulb is depressed, the invaginated surface becoming superficial, the bulb becoming more globular in shape, the position of the entrance of the duct being shifted to the dorsal side of the bulb, and the duct extending directly to the ectal surface. Apparently the cells of the bulb are all of one kind, and all extend to the surface of the bulb, none having been found emptying into the duct.

Spermathecæ.—A pair of these organs is present in V. Each spermatheca (Pl. CII, Fig. 35) consists of a well-defined duct and an ampulla. The ectal opening of the duct is in the intersegmental groove IV/V, and is latero-ventrad in position. No definite glands are present at the ectal opening. The wall of the duct is thick, and shows a number of large nuclei scattered throughout its length. The lumen is very fine. The duct is nearly straight, extending directly to the dorsal side of the digestive tract, where it expands to form the ampulla. The ovoid ampulla forms a closed sac, having no connection with the digestive tract. Its walls are quite thin, and in all of the specimens examined it was partially or entirely filled with sperm cells.

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EXPLANATION OF PLATES

Abbreviations

bl. s., blood sinus.
chl. c'l., chloragog cells.
chy. c'l., chylus cell.
cil., cilia.
cl. c'l., clitellar cells.
cut., cuticula.
en.ep.c'l., ental epithelial cell.
hyp., hypodermis.
in.b.c'l., inner bulb cells.
in.c'l.c'n., intracellular canal.
l.cyt., lining layer of cytoplasm.
m., musculature.
n., nucleus.
p., peritoneum.
p.b.s., perivisceral blood sinus.
pen.b.i., penial bulb invagination.
pen. lum., penial lumen.
pen. po., penial pore.
per.gl.c'l., peripheral gland cells.
r.m., retractor muscle.
sp.d., sperm duct.

Plate XCVIII

Fridericia firma

Fig. 1. Outline of anterior end, lateral view.
Fig. 2. Seta.
Fig. 3. Superficial section of the clitellar cells.
Fig. 4. Outline of brain, dorsal view.
Fig. 5. Outline of nephridium.
Fig. 6. Part of transverse section of intestine in chylus cell region.
Fig. 7. Chylus cell, greatly enlarged.
Fig. 8. Outline of spermiducal funnel.
Fig. 9. Longitudinal section, oblique to sagittal plane, through lower part of bulb

Plate XCIX

Fridericia firma—cont.

Fig. 10. Penial bulb in a transverse section of the worm.
Fig. 11. Outline of spermatheca.

Fridericia tenera

Fig. 12. Outline of anterior end, lateral view.
Fig. 13. Superficial section of clitellar cells.
Fig. 14. Seta.
Fig. 15. Outline of brain.
Fig. 16. Glands in the hypodermis.

Plate C

Fridericia tenera—cont.

Fig. 17. Outline of nephridium.
Fig. 18. Longitudinal section of intestine in chylus cell region.
Fig. 19. Outline of spermiducal funnel.
Fig. 20. Penial bulb in a transverse section of the worm.
Fig. 21. Outline of spermatheca.

Fridericia agilis

Fig. 22. Outline of brain, dorsal view.
Fig. 23. Longitudinal section of intestine in chylus cell region.

Plate CI

Fridericia agilis—cont.

Fig. 24. Outline of nephridium.
Fig. 25. Outline of nephridium of the type in which the postseptal part is reflected cephalad.
Fig. 26. Outline of spermiducal funnel.
Fig. 27. Penial bulb in transverse section of the worm.
Fig. 28. Outline of spermatheca.

Marionina forbesæ

Fig. 29. Outline of anterior end, lateral view.
Fig. 30. Lymphocytes.

Plate CII

Marionina forbesæ—cont.

Fig. 31. Seta bundle.
Fig. 32. Outline of brain, dorsal view.
Fig. 33. Outline of nephridium.
Fig. 34. Penial bulb in a transverse section of the worm.
Fig. 35. Outline of spermatheca.

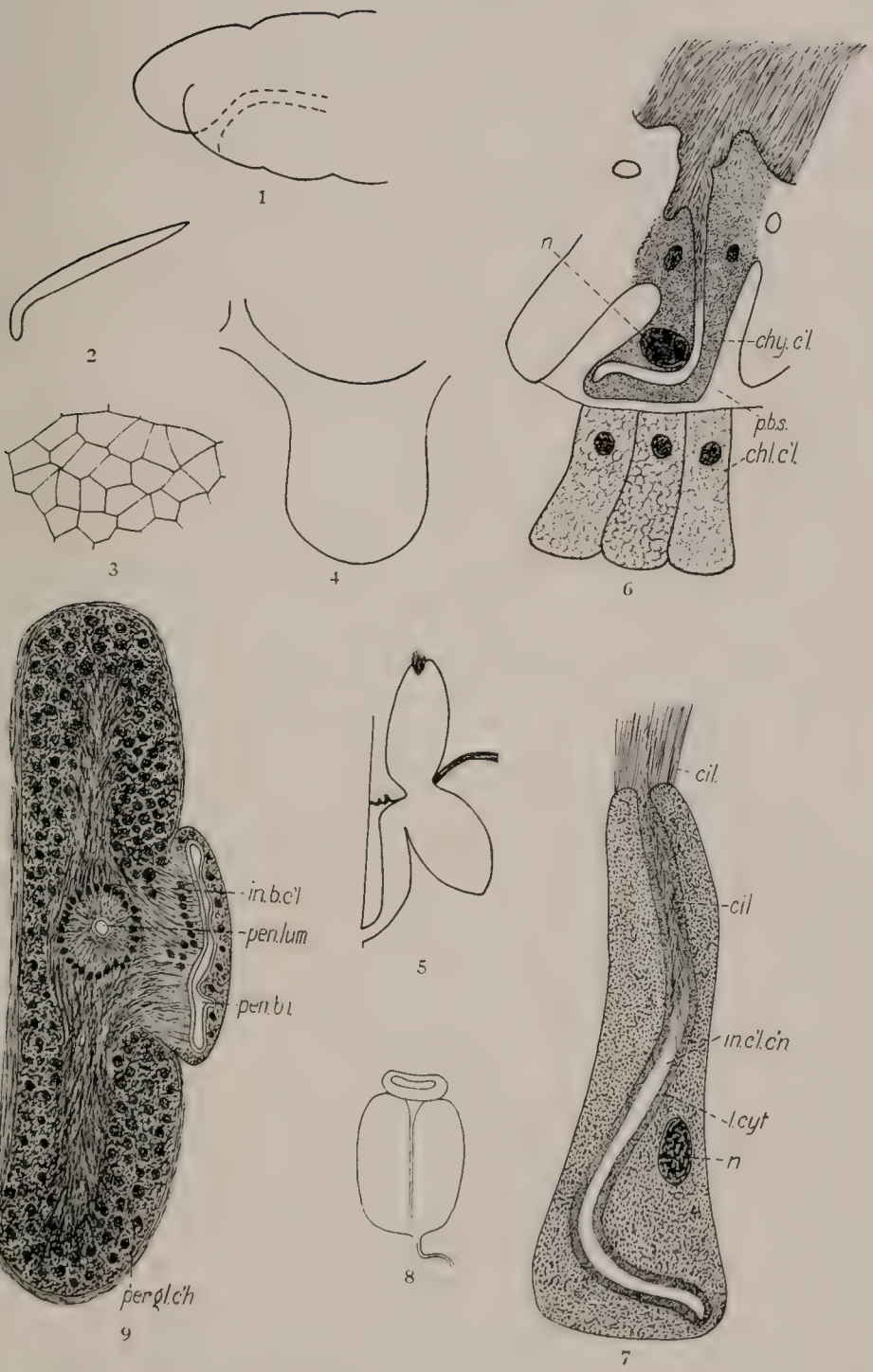
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Plate XCIX

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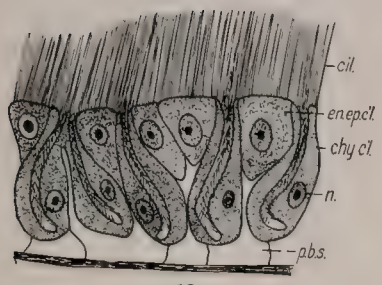

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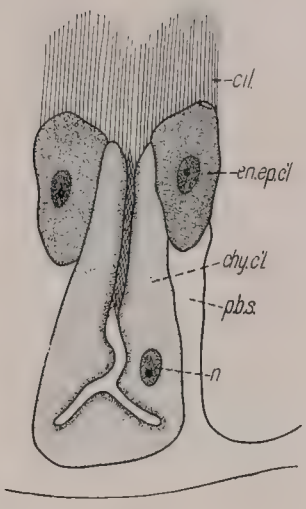

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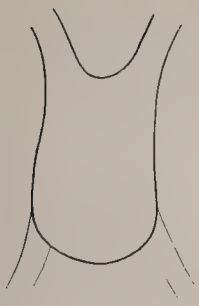

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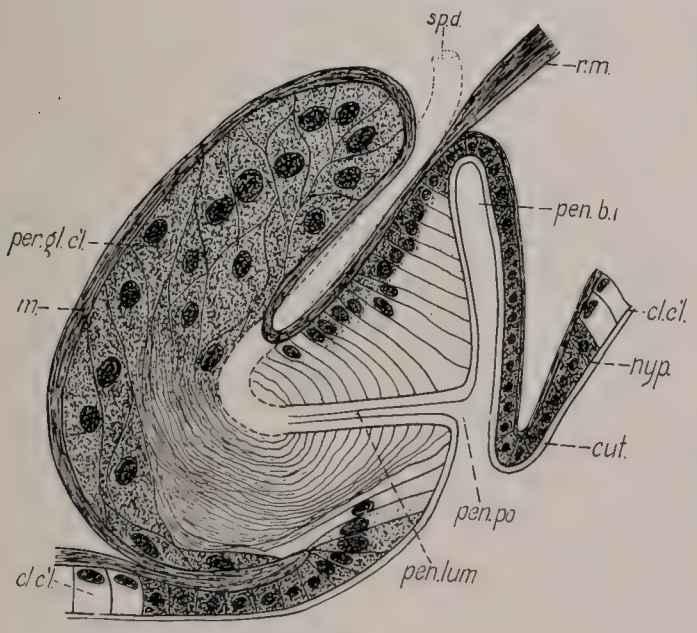

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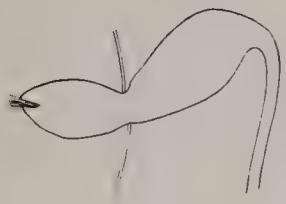

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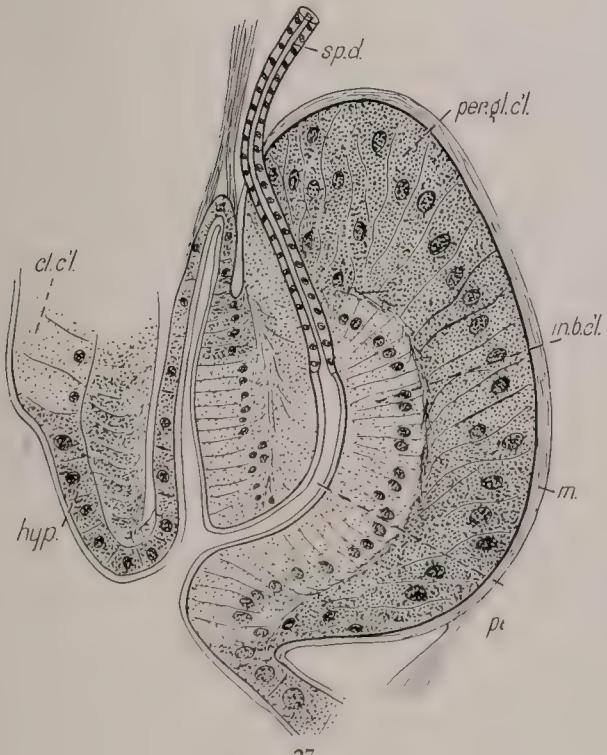

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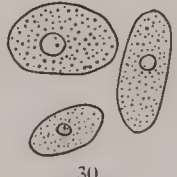

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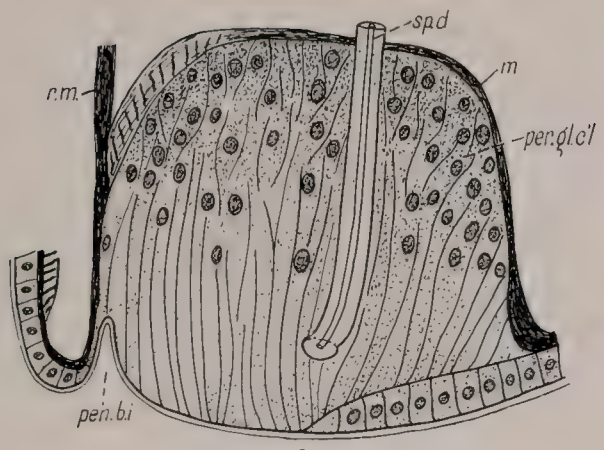

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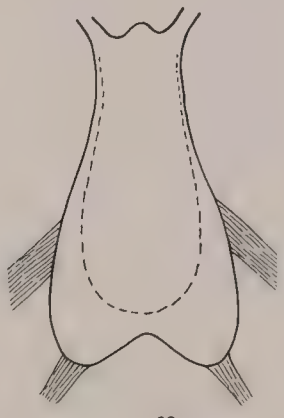

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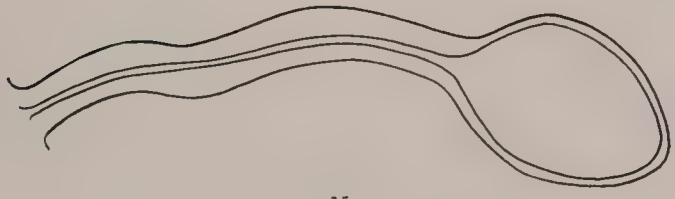

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BULLETIN

OF THE

ILLINOIS STATE LABORATORY

OF

NATURAL HISTORY

URBANA, ILLINOIS, U. S. A.

VOL. IX. APRIL, 1914 CONTENTS AND INDEX

1910–1913

ERRATA AND ADDENDA

Page 54, lines 3 and 2 from bottom, and elsewhere in Article III, for *Cassia chamaechrista* read *Cassia chamaecrista.*
Page 62, between lines 4 and 5 from bottom of table insert *Erigeron annuus.*
Page 101, table, after *Croton glandulosus* read var. *septentrionalis;* and for *Equisetum laevigatum* read *Equisetum hyemale* var. *intermedium.*
Page 131, line 3, for *coerulea* read *caerulea.*
Page 138, last line, for *Ziza* read *Zizia.*
Page 141, line 21 from bottom, dele *Diodia teres.*
Page 169, between lines 3 and 4, insert as follows:
Erigeron annuus (L.) Pers. An interstitial in the bunch-grass association in the Hanover area.
Page 177, line 5, for *eastward* read *westward.*
Page 209, line 3 from bottom, for *copalina* read *copallina.*
Page 210, line 13 from bottom, for *Diospyrus* read *Diospyros.*
Page 211, line 5, for *Foresteria* read *Forestiera.*
Page 256, line 3 of table, for Dr. H. *M.* Pepoon read H. *S.* Pepoon.
Page 278, line 16, the fifth word should be in Roman type.
Page 286, line 6 (second column), page 295, list of secondary species (second column), and page 353, line 8 from bottom, for *hiemalis* or *hiemale* read *hyemale.*
Page 313, line 4 from bottom (first column), for *pedicularis* read *pedicularia.*
Page 315, line 10, second column, for *Apocynum* read *Apocynum.*
Page 323, line 3 from bottom, for *Cyperus* read *Scirpus.*
Page 330, line 14, for *virginianum* read *virginicum.*
Page 336, lines 3 and 2 from bottom, for *virginicum* read *virginianum.*
Page 337, line 2 from bottom, for *philadelphicum* read *philadelphicus.*
Page 339, in first list of invading species, for *Rhus hirta* read *Rhus typhina.*
Page 351, line 4 from bottom, for *xerophtic* read *xerophytic.*
Page 355, above line 6 from bottom, insert *Scirpus heterochaetus* Chase.
Page 356, line 14 from bottom, for *Symlocarpus* read *Symplocarpus.*
Page 360, line 14, for *Pirus* read *Pyrus.*
Page 362, after line 7, insert *Acer saccharinum* L.
Page 363, line 2 from bottom, for *quadiflorum* read *quadriflorum.*
Page 365, line 14, for *thapus* read *thapsus.*
Page 369, last line, for *Tanecetum* read *Tanacetum.*
Page 417, line 1, dele *the.*
Page 497, line 9 from bottom, for *neglible* read *negligible,* and in foot-note, for *Austalt* read *Anstalt.*
Page 498, line 4 from bottom, for *Lockport* read *Chillicothe.*
Page 500, line 13 from bottom, after *up* insert *in.*
Page 501, line 2 from bottom, for *dissolving* read *dissolved.*
Page 504, line 23, for *gryina* read *gyrina;* line 17, for *dentata* read *knickerbockeri.*
Page 506, line 11, for *vernata* read *ternata.*
Page 507, line 3 from bottom, for *Mazon* read *wagon.*
Page 513, line 19, for *Nepa* read *Zaitha;* line 18, and page 517, line 13 from bottom, page 520, line 12 from bottom, and page 532, line 4, read *naid* or *naids* for *naïd* or *naïds.*
Page 517, line 6 from bottom, for *pondweed* read *pickerel-weed.*

Page 519, for first sentence of last paragraph read as follows:

We have no exactly comparable chemical data for July; but analyses for August give percentages of saturation for Morris and Marseilles as follows: 20.4 per cent. at Morris on the 11th and 11 per cent. at Marseilles on the 12th; 16.35 per cent. at Morris on the 22d and 23d and 7.4 per cent. at Marseilles on the 24th and 25th.

Page 521, line 6 from bottom, and page 529, line 9, for *chrysoleucas* read *crysoleucas.*

Page 525, line 22, and page 536, lines 21 and 24, for *Ekmann* read *Ekman.*

Page 532, line 1, for *Ancyclus* read *Ancylus.*

Page 551, line 7, for *00* read *512.*

Page 615, second line above foot-note, for *106* read 94.

Page 616, line 1, for the second *Bündeln* read *Bündel;* line 2, for *Bündeln* read *Bündels;* line 3, for *aussern* read *ausseren;* line 6, for *zweierlie* read *zweierlei.*

Page 629, line 12, for *kein* read *keinen.*

Page 634, line 9, for *unternommen* read *unternommenen;* and in line 14 from bottom, after *575* insert *13 fig.*

Plate III, Fig. 1, after the word *mixed* in legend insert *consocies of the.*

Plate IX, Fig. 2, dele the legend and read instead: Root-system of *Tephrosia virginiana,* exposed by blowing of the sand.

Plate X, Fig. 2, dele the legend and read instead: A blowout almost stabilized by bunch-grasses, especially *Leptoloma cognatum.*

Plate XXXIX, for *Calamogrostis* read *Calamagrostis.*

Plate LIV, exchange places of cuts, but not the legends.

Plate LXXXV, for *7* read *7c.*

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